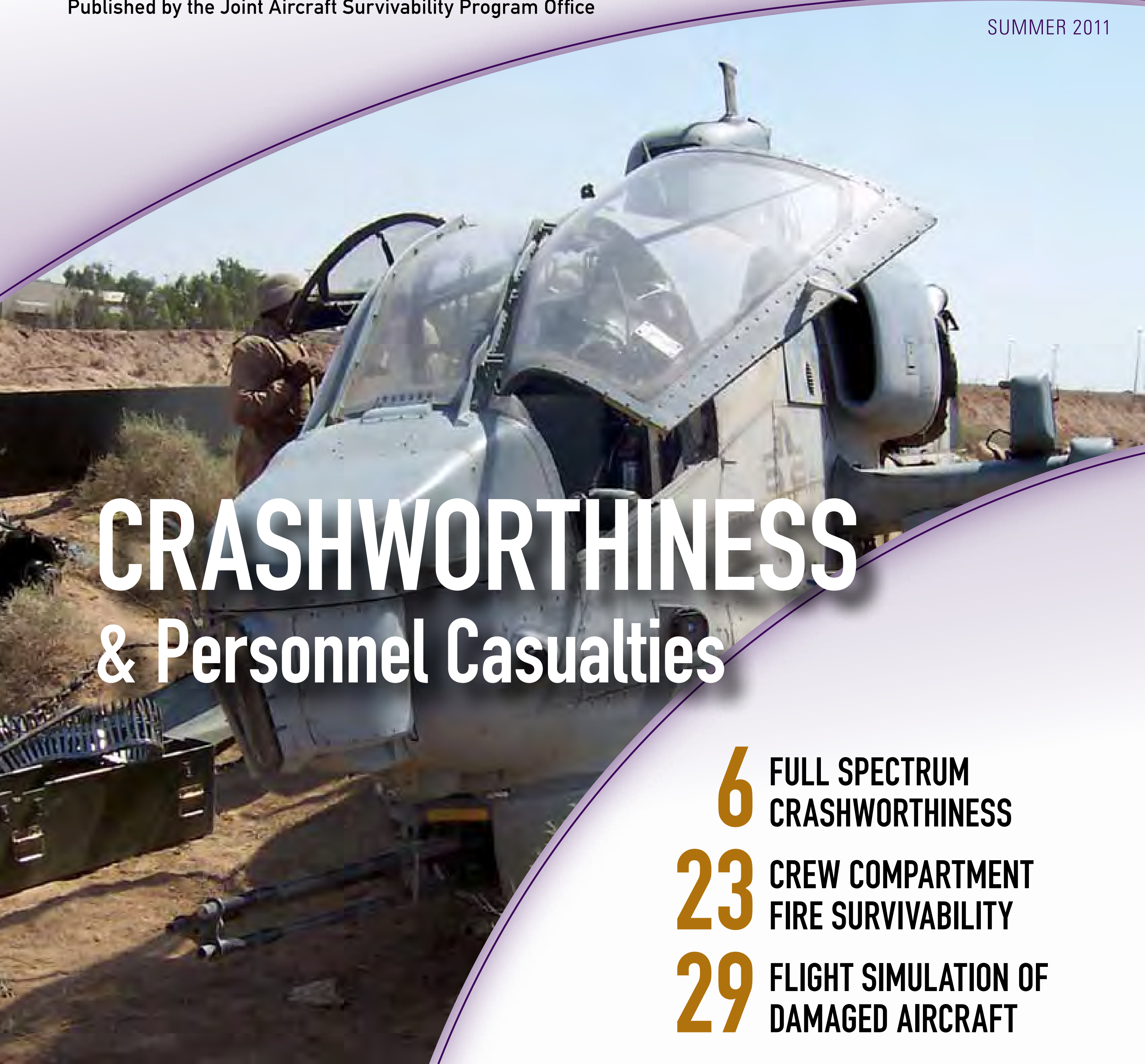
AIRCRAFT SURVIVABILITY

Published by the Joint Aircraft Survivability Program Office

SUMMER 2011



CRASHWORTHINESS
& Personnel Casualties

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**
4. TITLE AND SUBTITLE **Aircraft Survivability: Crashworthiness & Personnel Casualties**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **JAS Program Office,200 12th Street South,Crystal Gateway #4, suite 1103,Arlington,VA,22202**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**33**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Aircraft Survivability is published three times a year by the Joint Aircraft Survivability Program Office (JASPO) chartered by the US Army Aviation & Missile Command, US Air Force Aeronautical Systems Center, and US Navy Naval Air Systems Command.

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On the cover:

Marines prepare to recover the wreckage of an AH-1W Super Cobra in Iraq. Survivability features built in allowed the crew to walk away with just abrasions and bruises. JCAT analysis helped the Marines makes adjustments to reduce future susceptibility of their aircraft in combat.

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Crash investigations from the Vietnam War suggested that while helicopter crashes were potentially survivable events, occupants often did not survive due to failures of certain subsystems. Occupants able to survive the initial impact often perished in the post crash fire. Flailing injuries and spinal injuries further reduced their ability to egress and could have been mitigated with better restraints and stroking seats. The knowledge gained from studying Vietnam crash data was consolidated into the Crash Survival Design Guide (CSDG), which provided guidance on key areas that enable crash survivability.

In December 2009, a full-scale crash test of a small MD-500 helicopter was performed at the NASA Langley Landing and Impact Research (LandIR) Facility to investigate the effectiveness of an expandable honeycomb cushion called the Deployable Energy Absorber (DEA) in mitigating aircraft impact loads to survivable levels. The objectives of the crash test were to demonstrate the capabilities of the DEA under severe combined forward and vertical velocity conditions and to generate test data for validation of a system-integrated finite element simulation of the crash. [1-3] Dr. Sotiris Kellas, a senior aerospace engineer at NASA Langley, invented, patented, and developed the DEA concept.

The Joint Aircraft Survivability Program (JASP) is pleased to recognize Kevin Crosthwaite for Excellence in Survivability. Since 1993, Kevin has served as the Director of the Survivability Vulnerability Information Analysis Center (SURVIAC) located at Wright-Patterson Air Force Base, OH, which is operated by Booz Allen Hamilton. Kevin, a native of Ohio, graduated from Ohio State University (OSU) with a Bachelor of Science degree in Engineering Physics. He continued his studies and obtained a Master of Science degree in Nuclear Physics, also from OSU, and he is a licensed professional engineer in the state of Ohio.

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Distribution Statement A:
Approved for public release; distribution unlimited, as submitted under NAVAIR Public Release Authorization 11-791.

by Dennis Lindell

New Army Representative and Susceptibility Reduction Deputy Program Manager

Timothy Oldenburg "TO" joined the program office in March 2011. Tim is an Army representative from the Army Applied Technology Directorate (AATD) and the Deputy Program Manager for Susceptibility Reduction. He graduated from California State University, Fresno, with a MS in Mechanical Engineering (1997) and University of Arizona with a BS in Aerospace Engineering (1987).

Prior to joining the US Air Force, Tim worked for (then) McDonnell-Douglas Aircraft Corporation as a Stability & Control Engineer (1988–1990). He attended USAF Officer Training School (OTS) then went to work for the US Army Training & Doctrine Command (TRADOC) in the Air Combat Command (ACC) Liaison Office at Fort Leavenworth, KS, as a modeling & simulation specialist developing USAF/USA war game scenarios.

After Leavenworth, Tim worked as Lethality Analyst to assess weapons delivery accuracy on the Tri-Service Standoff Attack Missile (TSSAM) program. Tim flew as a B-52H Flight Test Engineer for 3 years while working on the B-2 developmental/operational test and evaluation test team as chief of the Armament section for testing and evaluating conventional, guided and nuclear weapons integration efforts. He was selected to become the Royal Australian Air Force (RAAF)/USAF Exchange Officer for Stores Clearance at the Australian Research and Development Unit (ARDU) in Adelaide, South Australia. There he managed the design, integration, certification and clearance efforts for all stores/weapons on RAAF F-111, F/A-18 Hornet, BAE Hawk and P-3C Orion aircraft. Tim transferred to Tyndall AFB, FL, to work at the Weapon System Evaluation Program (WSEP) as an operations analyst/engineer to assess aircrew tactics, techniques and procedures for engaging air-to-air and air-to-ground targets and analyze air-to-air missile performance to improve effectiveness.

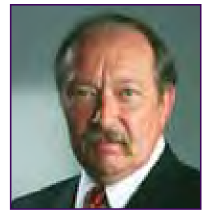
Tim moved to Robins AFB, GA, to work at the F-15 System Program Office upgrading/updating avionics equipment and ensuring depot maintenance technical practices/procedures are followed to maintain airworthiness of the F-15 fleet. Tim then moved to the F-35 Joint Strike Fighter (JSF) Program Office and worked as the avionics design integration chief, training development IPT lead, and deputy for systems, engineering and integration.

After retiring from the Air Force as a Lt Col, Tim worked for the Defense Threat Reduction Agency (DTRA) – Cooperative Threat Reduction (CTR) as the lead for acquisition processes in requirements analysis, design development and materials allocation of biological threat reduction and WMD proliferation prevention infrastructure.

Please join us in welcoming TO to the Joint Aircraft Survivability Program.

Walbert Receives NDIA Hollis Award

Dr. James Walbert has been awarded the National Defense Industrial Association's 2011 Walter W. Hollis Award for lifetime achievement in



defense test and evaluation (T&E). The award was presented at the organization's 27th Annual Test & Evaluation Conference, in Tampa, FL, 14–17 March 2011.

A mathematician with nearly four decades of experience in Department of Defense (DoD) T&E and related areas, Dr. Walbert serves as the Chief Scientist for the SURVICE Engineering Company, headquartered in Belcamp, MD. His experience includes extensive and novel work as an interior and exterior ballistician, vulnerability/lethality tester and analyst, materials engineer, author, and educator.

In receiving the award, the 64-year-old native of Maxatawny, PA, stated, "Just the thought of my name in the same sentence as Walter Hollis is overwhelming. And when I look at the names of the previous winners, I am even more humbled." Previous Hollis Award recipients include Dr. Jim Streilein, Dr. Ernest Seglie, Dr. Paul Deitz, Mr. Jim O'Bryon, RADM Bert Johnston, the Honorable Thomas Christie, Dr. Marion Williams, Mr. James Fasig, Mr. G. Thomas Castino, the Honorable Philip Coyle, and Mr. Walter Hollis himself.

"I have been so fortunate," Walbert added, "to have worked for and with people who understood the notion of critical thinking; people who would rather build an 'App' than buy one; and people who asked basic questions and strove to understand basic principles."

From 1974 to 1978, Dr. Walbert served as a mathematician and test director for the US Army Material Testing Directorate, where he planned, analyzed, evaluated, and assessed a wide range of engineering test programs. From 1978 to 2000, he

served as a research scientist/engineer for the US Army Ballistic Research Laboratory (BRL) (and its successor organization, the Army Research Laboratory [ARL]), where he investigated interior ballistic phenomena, conducted engineering assessments of combat vehicle survivability, conducted Live Fire testing of US and foreign combat vehicles, and analyzed projectile and missile performance data. He also served as a branch chief and the chairperson of the Active Protection Systems portion of the Army/Marine Corps/Defense Advanced Research Projects Agency(DARPA) Armor/Anti-Armor Program.

While in BRL's Interior Ballistics Division, Dr. Walbert devised the means for determining the motion of projectiles in-bore, including balloting and spin-up. For this work, he was awarded the Army Research and Development Achievement Award in 1984. He also helped to document the shot-impact patterns of various tank-fired projectiles. The analysis of these phenomena formed the basis for the BRL Tank Gun Accuracy program and led to the re-assessment of the manner in which gun tubes were fabricated. This work also led to Dr. Walbert's selection as co-recipient of the Army Research and Development Achievement Award in 1985.

As Program Manager for Joint Live Fire Armor/Anti-Armor, Dr. Walbert was responsible for the testing and evaluation of US and foreign threats and targets. This work included developing a team of damage assessors trained in foreign systems. This team formed the core of analysts for field data collection in the first Gulf War and set the precedent for all field assessments.

Dr. Walbert also served on the special projects team of ARL's Weapons and Materials Research Directorate, where he was an Army agent for the Ballistic Missile Defense Organization and helped develop and test methods for using composite materials in missiles.

From 2001 to 2003, Dr. Walbert served as the first Chief Scientist in the Future Combat Systems (FCS) Program Office at the DARPA. Here he assessed technologies suitable for application to the Army's Objective Force, as well as the DoD technology base for applicability and maturity of technologies to FCS. He was also the Program Manager for the DoD Joint Live Fire Program and was the DARPA lead on the Science and Technology IPT. In addition, he provided technical support to the Electronic Warfare IPT, a Joint Service team providing recommendations on all aspects of electronic warfare and directed energy weapons.

Since joining SURVICE in 2003, Dr. Walbert has developed analytical processes for exploitation of ballistic test data, including the application of numerical filters and Fourier analysis to structural and anthropomorphic simulator test data. He formulated the JTCG/ME and THOR penetration equations for kinetic energy threats against an array of materials into equations suitable for use in desktop calculations, and he devised the methodology for extending these equations to threats and materials beyond their original scope. Furthermore, he has developed ground-breaking methodology for analyzing the survivability of networked combat systems, and he has developed a theory of combat power that is being implemented in a force-level simulation. He also serves as a consultant to the Army Science Board.

Dr. Walbert has authored/co-authored more than 50 technical publications during his career, including the AIAA-published text *Fundamentals of Ground Combat System Ballistic Vulnerability/Lethality*, which was named ARL's Publication of the Year in 2009. He also developed and currently teaches a highly acclaimed ballistic vulnerability/lethality course, "V/L 101," to practitioners throughout the T&E community.

Dr. Walbert's education includes a BS, MS, and PhD in mathematics from the University of Delaware. In addition, he has taught mathematics and/or engineering at the University of Delaware, Penn State University, and Marymount University. When not at work, he enjoys wood carving (wild fowl) and model railroading. He lives with his wife, Lana, in Occoquan, VA. ■

JCAT Corner by CW4 Bryon "Mac" McCrary, USA *(With input from the Service Leads)*

It would seem that change is the only constant these days, and as we enter the spring of a new year it remains true for the Joint Combat Assessment Team (JCAT). While the primary focus in theater has shifted, the direction, dedication and hard work in support of two areas of responsibility (AOR), the Survivability Community and most importantly, to the War Fighter, has not. JCAT has adapted to the changes, closing up shop in Iraq while simultaneously pushing more personnel to support what has been a very busy year in Afghanistan.

The US Air Force (USAF) contingent of JCAT continues to broaden its experience base, two new members have deployed to Operation Enduring Freedom (OEF). Maj Nick Hardman is serving on Bagram Airfield, performing as the JCAT lead for the OEF region. As a graduate of USAF Test Pilot School, Major Hardman brings a wealth of operational experience to the team. His background as an electrical engineer, coupled with a PhD in Systems Engineering, generates an in-depth technical analysis capability not normally encountered in the AOR. Also, he is well-versed in tactical defensive avionics systems for the F-15E/B-1B, which will enhance Air Force analysis of electronic warfare (EW) system response. In addition, he has a background in unmanned aerial vehicle (UAV) systems, a first for the JCAT. Major David Garay, who is currently assigned to Kandahar Airfield, is another addition to the deployed AF JCAT. Major Garay is also a graduate of the USAF Test Pilot School. He specializes in weapons delivery and effects, and has also conducted numerous projects evaluating precision guided munitions. Both members will bring an enhanced analytical

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Full Spectrum Crashworthiness for Rotorcraft

by John Crocco

Crash investigations from the Vietnam War suggested that while helicopter crashes were potentially survivable events, occupants often did not survive due to failures of certain subsystems. Occupants able to survive the initial impact often perished in the post crash fire. Flailing injuries and spinal injuries further reduced their ability to egress and could have been mitigated with better restraints and stroking seats. The knowledge gained from studying Vietnam crash data was consolidated into the Crash Survival Design Guide (CSDG), which provided guidance on key areas that enable crash survivability.

MIL-STD-1290, ADS-11, and ADS-36 are standards to meet a certain level of crashworthiness. These standards were based on the guidance provided in the CSDG, but could be referenced as requirements for aircraft to meet. Over the years, the CSDG and military standards were updated and revised. Other standards were created for specific subsystems (such as pilot seats, inertia reels, landing gears) and subsequently revised. Revisions were made to ensure advances made in technology would be captured by the requirements specified. In the mid-1990s, due to acquisition reform, all of these standards were canceled.

In the Army's fleet of rotorcraft, only two have ever been qualified to military standards for crashworthiness: the UH-60 and AH-64. Both were designed to meet MIL-STD-1290. ADS-36 was written specifically for Comanche, but relied significantly on MIL-STD-1290. The OH-58, ARH-70 and UH-72 where designed to FAA part 27 crash standards, as their commercial counterparts where originally designed to meet those less stringent requirements. Other Army helicopters have incorporated crash protection features over time, but the aircraft systems as a whole were not designed to meet crash requirements as described in the CSDG or any military standard.

The requirements of MIL-STD-1290 are based on practical assessments that could be analyzed and tested at the time it was developed. The requirements primarily ensure the airframe and subsystems resist damage when impacting either a rigid vertical barrier or a rigid surface. Setting up the test conditions to meet these requirements is relatively straight forward and simple to evaluate. One requirement involving a low angle impact into plowed soil was to ensure that plowing and scooping did not occur (thus increasing the deceleration of the aircraft). As such the capability was demonstrated by identifying anti-plow mechanisms in the design, not necessarily conducting a test. Structures are designed to static load criteria that, if met, reduce the likelihood of structural failure. Meeting MIL-STD-1290 requirements would necessarily create a more crashworthy helicopter than one not designed to these requirements. The crash mishap data for the UH-60 and AH-64 reflect this. [1] Regardless, there are some limitations to the MIL-STD-1290 requirements. MIL-STD-1290 focuses on light- to medium-size rotorcraft, and doesn't necessarily scale up to larger heavy lift rotorcraft. Meeting the static loading criteria on a heavy lift rotorcraft may not be feasible. Meeting the requirements for impacting a rigid surface caused designs to focus on ensuring landing gears absorbed a large percentage of the impact energy. The requirements were also based on the assumption that the crash occurs at structural design gross weight with only the crew aboard. As the historical data shows, this scenario rarely occurs. A preliminary kinematic study of Army rotorcraft mishaps was concluded in 2005. [2] One of its conclusions was that 7% of Army crash mishaps occurred on a surface that could be considered "MIL-STD-1290 representative" (*i.e.* rigid). A majority of the crashes occurred on sod or soft soil. There are also operating realities that don't match MIL-STD-1290 requirements. Aircraft operational weights can vary significantly and change over the mission profile. Crashes can occur in many different environments. Occupant protection is just as critical as crew protection. Future vertical lift requirements only exacerbate the inconsistencies. Joint service aircraft will operate over water as well as urban and rural environments. A recent Joint Heavy Lift study showed that the variation of aircraft weights could be on the order of 25 tons depending on the mission, with large variations in center-of-gravity (CG) as well. Rotorcraft such as tilt-rotors or compound aircraft fly differently and most likely crash differently than the MIL-STD-1290 scenarios. Finally, prescriptive requirements are always chasing technology improvements (requiring revisions to requirements). There have been dramatic technology improvements in the last 15 years, yet requirements have remained the same and may not reflect how these technologies can improve crashworthiness. Non-prescriptive, technology agnostic crashworthiness requirements are needed.

The Aviation Applied Technology Directorate (AATD) led the Full Spectrum Crashworthiness (FSC) effort to refine crashworthiness requirements that represent more realistic crash conditions. This effort was conducted with the Center for Rotorcraft

Innovation (with participation from Bell, Boeing, Sikorsky, and Kaman), SAFE, Inc., and Intuitive Research and Technology Corporation. A steering group was set up that included representation from the Aviation Missile Research Development and Engineering Center, Navy, NASA, FAA, Air Force, and the Army Concepts Requirements Directorate. The multiple task effort looked at historical crash mishap data, future concept of operations estimates, currently available and on-the-horizon technologies, the state of modeling and simulation tools, and system level approaches to design for crashworthiness. The products of this effort included design guidance for future rotary wing aircraft, a technology roadmap, and a methodology to evaluate crashworthy designs, which has come to be known as the Crashworthiness Index (CI). Under this effort, crashworthiness was defined as:

"The ability of an aircraft to maintain a protective space for occupants throughout the crash impact sequence; prevent occupants, cargo, or equipment from breaking free of their normal location and positions during a crash sequence; limit the magnitude and duration of accelerations and loads experienced by occupants to within survivable levels; prevent catastrophic injuries and fatalities resulting from contact with barriers, projections, and loose equipment; and limit the threat to occupant survivability posed by fire, drowning, exposure, entrapment, etc., following the impact sequence."

Full Spectrum Crashworthiness

Based on the research conducted under FSC, a methodology to calculate a CI was developed. Based on historical mishap data of Army rotorcraft:

- Rotorcraft tend to crash with a high vertical component. In a crash that involves an in-flight impact (wire strike, collision) the vertical component is noticeably higher. There is also a trend towards an increase in the percentage of mishaps that involve in-flight impacts for modern (UH-60/AH-64) rotorcraft compared to older models such as the Huey and Cobra.
- The aircraft weight at impact varies, and over time the trend is toward an increasing weight at the time of impact.
- Pitch and roll can affect the performance of crash protection systems, especially if landing gears play a large role in energy attenuation. Less than 70% of crash mishaps occur within the envelope addressed by MIL-STD-1290 requirements (Figure 1, green envelope). Less than roughly 35% of impacts occurred at "level impact" conditions (nominally 0 pitch/0 roll). Capturing 100% of pitch roll conditions is not feasible. It was also noted that 80% of the army crash mishaps occurred between +20 /-10 degree pitch and +/-20 degree roll (Figure 1, blue envelope).

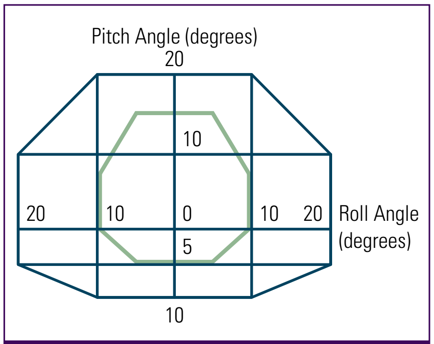

Figure 1 Pitch / Roll Envelopes

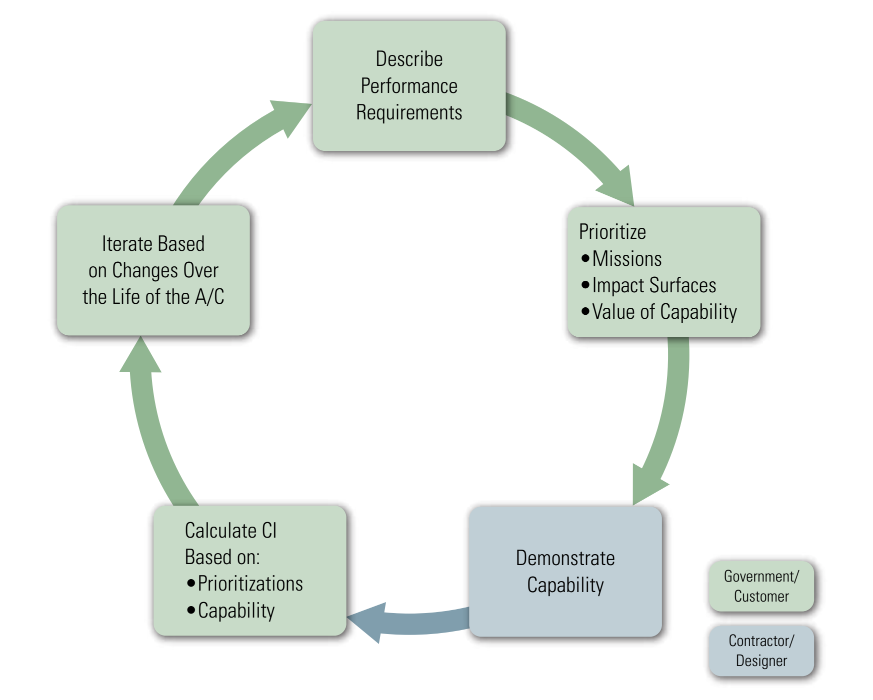

Figure 2 FSC Methodology

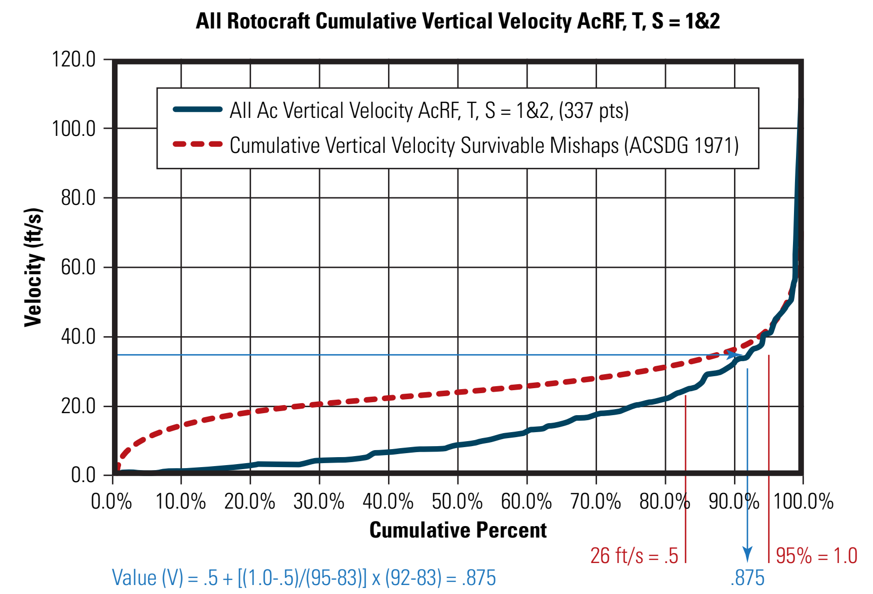

Figure 3 Value of Impact Capability

➤ Army data has been fairly consistent with respect to the percent of time that a rotorcraft impacts a given surface type. Surfaces can be grouped into three general categories: rigid (which can be a hard, prepared surface or a flight deck) is impacted 16% of the time; water (which includes anything from shallow water to ocean) is impacted 4% of the time; and soft soil (which can include soggy ground, marshes or desert sand) is impacted 76% of the time. Future operations could change this trend and joint sea-based missions could increase water mishap events for Army rotorcraft.

The FSC steering group reviewed this data, reviewed the state-of-the-art for crash protection technologies, modeling and simulation tools, and assessed where technologies and analysis tools where headed. The CI was developed as a way to evaluate any rotorcraft's ability to provide crashworthiness to its occupants.

Crashworthiness Index

The CI is a quantitative measure of a rotorcraft's crashworthiness across multiple crash environments and conditions. It is a calculation based on multiple crash conditions and system performance under those conditions. The CI is capable of being a design tool or a comparison tool among various designs. The CI is flexible enough to reflect service specific as well as Joint service requirements, and can be adapted to evaluate future unknown missions. The process for calculating the CI and designing for full spectrum crashworthiness (Figure 2) starts with the customer describing their performance requirements, identifying probable mission scenarios, prioritizing possible impact conditions, and setting threshold and objective capabilities. Based on these inputs, a designer can demonstrate the extent that their specific platform meets the requirements. Over the life of the aircraft the CI can be updated based on new customer needs, changes in missions or environments, or aircraft improvements.

The CI is a numerical measurement of the crash performance of a specific aircraft design crashing in a relevant environment at a most probable weight. The CI can be weighted based on the customer's specific performance requirements and the probability of impacting a certain surface (water, soil, rigid). There are three factors that can be measured to calculate crashworthiness. The FSC approach is occupant centric. Rather than specifying structural requirements for crash resistance, as in MIL-STD-1290, performance requirements are set based on ensuring occupant survivability. These requirements focus on ensuring occupants:

1. Survive the impact loading
2. Have a survivable volume around them after the crash
3. Are able to safely egress and survive until rescued

An Occupant surviving impact loading is demonstrated by ensuring loads on the human are within tolerable levels. Defining this requirement is work that is still ongoing and will be the subject of future papers. Demonstrating that a survivable volume is maintained requires a structural analysis of the airframe along with human/structure interaction. Demonstrating safe egress and post impact survivability requires identification and analysis of egress routes, identification of survivability equipment, and ensuring rescue operations are able to quickly respond. If you are able to demonstrate these at a specific impact speed, aircraft weight, pitch/roll attitude, onto a specific surface, you have crashworthiness in that scenario. If you are able to demonstrate these on any surface, at any weight, at all pitch/roll attitudes, and at any impact velocity, you have achieved the full spectrum of crashworthiness. The latter is neither cost effective, nor necessary. The FSC CI methodology requires the customer

Mission 1 (Cargo Resupply) GW/CG %

GW (lbs) \ CG STA (in)	540	600	660	720	780	840
120,000	45					
110,000		5				
90,000						45
70,000					5	

Mission 2 (Troop Transport) GW/CG %

GW (lbs) \ CG STA (in)	540	600	660	720	780	840
120,000						
110,000		35				
90,000			10	5		35
70,000				5	10	

Mission 3 (Vehicle Transport) GW/CG %

GW (lbs) \ CG STA (in)	540	600	660	720	780	840
120,000		35				
110,000			10			
90,000			10	35		
70,000			10			

Mission Combined GW/CG %

GW (lbs) \ CG STA (in)	540	600	660	720	780	840
120,000	20.25	12.25				
110,000		9.25	3.50			
90,000			5.5	13.25		27.25
70,000			3.5	1	4.25	

Mission 1	=45%
Mission 2	=20%
Mission 3	=35%
Combined	=100%

Figure 4 Value of Impact Capability

to identify those mission scenarios, environments and threshold and objective capabilities that they are most interested in. Once these are identified the designer can demonstrate to what extent their specific design meets those capabilities.

Crashworthiness Index Example Calculation

The following is an example of how this methodology could be applied. This example will be for a joint, long endurance, heavy vertical lift aircraft. The customer identifies three missions that are expected to be conducted: cargo resupply, vehicle transport, and troop transport. First, the customer prioritizes these mission scenarios, and determines how often, over the life of the aircraft, it will likely be conducting a specific mission (*e.g.* Cargo Resupply: 45% of total life, troop transport: 20% and vehicle transport: 35%). Next, the customer prioritizes the expected impact surfaces. For example, based on historical mishap data, Army aircraft will most likely crash in soft soil/rural environments (76%) then rigid surfaces (16%) then water (4%). Weighting factors can be set based on these percentages: 0.803 for soft soil, 0.172 for rigid surfaces, and 0.025 for water. By simply changing the weighting factors to include Navy statistics as well, the customer can see what the cost/benefits are of making a specific platform crashworthy and joint. The customer then sets threshold and objective impact capabilities (Figure 3). In this example, just the vertical impact capability will be evaluated, although other capabilities (low-angle impact, high-angle impact, vertical rigid barrier impact, *etc.*) can be prioritized as well. A threshold capability of 26 ft/sec vertical impact capability has been chosen here whereby there is no value (*i.e.* 0) demonstrating below this capability. Demonstrating a capability of 26 ft/sec provides minimum value (*i.e.* 0.5), and demonstrating the objective capability of the 95th percentile of all crash mishaps (38 ft/sec) is of full value (*i.e.* 1.0). Demonstrating a capability above 38ft/sec would provide a value greater than 1. Demonstrating a capability between 26 ft/sec and 38 ft/sec would provide value proportional to the mishap data (*e.g.* from Figure 3, 92nd percentile capability provides a value of 0.875).

Rigid Surface Performance (ft/sec)

GW (lbs)	540	600	660	720	780	840
120,000	20	22				
110,000		25	26			
90,000			29	28		32
70,000			30	32	36	

CG STA (in)

Water Surface Performance (ft/sec)

GW (lbs)	540	600	660	720	780	840
120,000	25	27				
110,000		30	31			
90,000			34	33		37
70,000			35	37	41	

CG STA (in)

Soft Soil Surface Performance (ft/sec)

GW (lbs)	540	600	660	720	780	840
120,000	30	32				
110,000		35	36			
90,000			39	38		42
70,000			40	42	46	

CG STA (in)

Low Probabability Conditions | Simplified Conditions

Figure 5 Vertical Impact Speed Capability Matrix

Rigid

GW (lbs)	540	600	660	720	780	840
120,000	L	L				
110,000		L	F			
90,000			F	F		L
70,000			F	F	L	

CG STA (in)

Water

GW (lbs)	540	600	660	720	780	840
120,000	F	F				
110,000		F	F			
90,000			F	F		F
70,000			F	F	F	

CG STA (in)

Soft Soil

GW (lbs)	540	600	660	720	780	840
120,000	L	L				
110,000		F	F			
90,000			F	F		L
70,000			F	F	F	

CG STA (in)

"F" Indicates Full Pitch and Roll Capability (MIL-STD-1290A)
PR Weighting Factor=1.0

"L Indicates Level Only Capability
PR Weighting Factor=.72

Figure 6 Pitch / Roll Capability Matrix

Table 1 Mission Score

Mission 2

GW (lbs)						
120,000	0	0	0	0	0	0
110,000	0	0.245339	0	0	0	0
90,000	0	0	0.086441	0.042323	0	0.239757
70,000	0	0	0	0.047149	0.097388	0
CG STA (in)	540	600	660	720	780	840

■ *Score = (0.172 x PRrigid x Vrigid + (0.025 x PRwater x Vwater) + (.803 x PRsoil x Vsoil)*

Sum: 0.758378 Score: 75.83777 (out of 100)

Table 2 Score for Combined Missions

A) Missions Combined

GW (lbs)						
120,000	0.078316	0.053243	0	0	0	0
110,000	0	0.06484	0.029698	0	0	0
90,000	0	0	0.047543	0.112156	0	0.186668
70,000	0	0	0.030873	0.00943	0.041381	0
CG STA (in)	540	600	660	720	780	840

Sum: 0.654 Score: 65.415 (Score variation indicates loss in fidelity due to simplifying mission profiles.)

B) Missions Reduced

GW (lbs)						
120,000	0.096687	0.086928	0	0	0	0
110,000	0	0	0	0	0	0
90,000	0	0	0	0.169292	0	0.239757
70,000	0	0	0	0	0	0
CG STA (in)	540	600	660	720	780	840

Sum: 0.593 Score: 59.266

With these prioritizations and requirements from the customer, the designer can now identify how the gross weight and CG of their design changes over the mission profile (Figure 4). Conducting an analysis for all possible weight and CG conditions is time and cost prohibitive. Identifying the key “high likelihood” conditions can greatly reduce the number of analysis. Those highlighted in brown could be called the high-likelihood conditions, those in grey are low likelihood, but relevant conditions. The designer can also identify which weight/CG conditions have crew and cargo only or crew and occupants.

Using validated analysis tools for the ‘hard to test’ conditions, and analysis and test for testable conditions, two matrices can be developed that show aircraft crashworthiness capability. The first (Figure 5) is a vertical sink speed capability on the various surfaces such as rigid, water, and soft soil. This sink speed capability will also be directly tied to a pitch/roll capability (Figure 6). Providing capability to the MIL-STD-1290 pitch/roll envelope will be weighted as providing 100% capability (PR factor = 1.0), while providing only level impact capability will be weighted as providing 72% capability (PR factor =0.72). Exceeding the MIL-STD-1290 pitch/roll envelope would provide needed capability and could be weighted with a higher factor. By providing adequate sink speed capability across the entire pitch/roll envelope, for the relevant weight and CG conditions, a greater spectrum of crashworthiness is obtained.

By combining the sink speed capabilities, the pitch/roll factors, and the surface weighting factors, a score for each condition and for each mission can be calculated relative to a maximum value (Table 1). Based on the time spent conducting each mission over the life of the aircraft, an overall score for the combined missions can be calculated (Table 2). Depending on the level of detail the designer chooses (or customer demands) calculations can be done for the entire weight/CG envelope (Table 2a) or a reduced set of conditions (Table 2b). Most importantly, none of these requirements are technology dependant. It is up to the designer to demonstrate a technology’s capability in supporting aircraft system crashworthiness. It is up to the customer to verify that a system meets their requirements.

As long as the mission scenarios and weighting factors remain constant, this methodology can be used to compare competitive rotorcraft, identify the costs and benefits of various crashworthiness technologies, and determine what they bring to provide the maximum, relevant protection. Over the life of an aircraft, as missions change, or as the operational environment changes, this tool can also be used to evaluate how crashworthiness is affected, and can identify areas where protection can be improved.

The complete methodology is still under development and is available at *www.dodtechipedia.mil* search keyword: Full Spectrum Crashworthiness. ■

About the Author

Mr. John Crocco works for the US Army at the Aviation Applied Technology Directorate (AATD), Ft. Eustis, VA. He received a BS degree in aerospace engineering from The Illinois Institute of Technology in 2002. Mr. Crocco has worked the last 8 years at the AATD for the Platform Technology Division on the structures team. His work includes ballistic testing of structural components, dynamic load and stress prediction, and development of new crashworthiness criteria.

References

1. Technical Report, RDECOM Technical Report 09-D-45, Rotorcraft Crash Mishap Analysis, prepared for US Army Research, Development & Engineering Command, Aviation Applied Technology Directorate, Fort Eustis, VA, by Safe, Inc., Tempe, AZ. May 2009.
2. Labun, Lance, “Final Report on the Survivable Affordable Repairable Airframe Program (SARAP) and the Helicopter Kinematic Design Criteria for Crashworthiness,” Simula Aerospace and Design Group, TD-04049, May 2004.

JCAT Corner
Continued from page 5

perspective to JCAT reporting for weapons effects – we are very proud they decided to join our team.

The Army JCAT has recently welcomed CW5 Brendan Kelly on board as the latest Aircraft Shoot-Down Assessment Team (ASDAT) Team Chief. Brendan comes to the team from PACOM with a broad range of experience in military aviation and survivability, most recently as the USARPAC Aviation Tactics Officer-in-Charge (OIC). As an AH-64D Apache Longbow driver and Tactical Operations Officer, he has multiple deployments under his belt and was a key player in the development and implementation of Tactical Terrain Visualization System (TTVS) into Army mission planning systems. His talents are a welcome addition to the team.

The Marine Corps JCAT is in the process of incorporating LtCol (Col Select) Mark Harrison into the fold. He has recently completed Phase I training at Fort Rucker while still Commanding Detachment 4-1 of 4th Civil Affairs Group. LtCol Harrison holds a degree in Mechanical Engineering Technology and is an Aircraft Maintenance Officer by specialty. In his civilian employment, LtCol Harrison works in the commercial aviation industry exercising his aviation and engineering backgrounds.

The Navy component would like to congratulate CAPT Bill Little who officially takes the helm as Commanding Officer on March 26th. CAPT Little brings a wealth of knowledge and leadership experience to his new position. He previously served as an assessor and OIC during Operation Iraqi Freedom and recently returned from a tour in Afghanistan as OIC for JCAT operations in that theater. Congratulations and welcome aboard!

With the JCAT members over-seas in high gear, the home front team has worked hard to prepare for future operations, providing refresher training for current members and training new team members. In September, the Army hosted a JCAT drill at Fort Rucker, AL. The drill provided an opportunity to conduct final coordination on the JCAT standard operating procedure (SOP), gather notes from the field and conduct weapons refresher training. A round-table discussion was conducted that included a teleconference with input from our deployed team members to refine and improve issues ranging from supply challenges and updating equipment, to operational support both in and out of theater. The meeting was followed by weapons refresher and advanced firing techniques classes that culminated out on the range on a hot, but thoroughly enjoyable afternoon of shooting. In November, the National Defense Industrial Association (NDIA) sponsored the Aircraft Survivability Symposium. Held at the Naval Postgraduate School in beautiful Monterey, CA, the symposium also had a large JCAT turnout. The week included aircraft survivability classes and highlighted government, industry, academia, and military successes in enhancing combat aircraft survivability and addressed future requirements and challenges to aviation warfighters. Finally, as this article is being written, final preparation is underway at Fort Rucker to welcome approximately 20 new students from across the services to JCAT Phase I training. Training will include introduction to rotary wing aircraft, fundamentals on weapons and photography basic skills. The students will also have the opportunity to piece together a scenario event that includes evidence from the ASDAT "bone-yard," to build and hone the skills they will require as deployed JCAT personnel.

Unfortunately change often requires that we say goodbye to very good people who have added immense value to our efforts, but must now move on to grow and excel in new opportunities. That being said, JCAT would like to take the opportunity to thank the following personnel for their service. Their efforts and dedication to the JCAT teams across all services have been greatly appreciated:

CAPT Kirby Miller, known throughout the JCAT family for his hard work, engaging personality, and most importantly for his leadership while serving as skipper for Navy JCAT, has been tasked to a new posting. However, fortune continues to smile on the JCAT community with CAPT Miller continuing to work in the survivability community as the deputy director of the Naval Air Systems Command (NAVAIR) Reserve Program, Patuxant River, MD, under the tutelage of another former JCATer, RDML Chuck Rainey. "Fair winds and following seas" CAPT Miller.

The Army JCAT component has had to say so long to two heavy hitters in less than six months. ASDAT Team-Chief CW5 Bobby Sebren volunteered to get his boots dirty and joined the 10th Combat Aviation Brigade in its deployment in the fall. Bobby's calm leadership style, sense of humor and hard work will be greatly missed. The up side of his departure is that his JCAT expertise is available to assist the other team members deployed in theater. After three years on the ASDAT Team, CW5 Michael (don't forget to add the E) Kelley, has been promoted to CW6, and unfortunately out of the team. His tour at Fort Rucker included multiple deployments in support of the JCAT mission, a short term as interim ASDAT Team-Chief, and many long hours in support of the JCAT mission. Mike is moving to Korea for a short tour as the Brigade Tactical Operations Officer. Best of luck Mike, and thanks for the hard work.

By the time this article has been put to bed and sent off to print the JCAT team will have completed the annual Threat Weapons and Effects (TWE) seminar at Hurlburt Field, FL. The Navy component sponsored the event this year and it will have included presentations from some of the leading authorities in the survivability field along with multiple live fire demonstrations. In anticipation of USCENTCOM operations slowly winding down in the near future, the goal this year was to begin focusing on threats in other potential "hotspots" around the world. If you were there we hope that expectations were met. If you couldn't make it this year or haven't attended in the past please mark a spot on your calendar for the next TWE in April of 2012. Look for exact dates and details in upcoming issues of this publication. ■

Deployable Energy Absorber for Improved Rotorcraft Crashworthiness

by Karen Jackson and Martin Annett

In December 2009, a full-scale crash test of a small MD-500 helicopter was performed at the NASA Langley Landing and Impact Research (LandIR) Facility to investigate the effectiveness of an expandable honeycomb cushion called the Deployable Energy Absorber (DEA) in mitigating aircraft impact loads to survivable levels. The objectives of the crash test were to demonstrate the capabilities of the DEA under severe combined forward and vertical velocity conditions and to generate test data for validation of a system-integrated finite element simulation of the crash. [1-3] Dr. Sotiris Kellas, a senior aerospace engineer at NASA Langley, invented, patented, and developed the DEA concept.

External energy attenuating devices, such as external airbag systems and the DEA, offer unique advantages for improving rotorcraft crashworthiness, either as stand-alone systems or in conjunction with a systems-level approach. [4, 5] Internally, crushable structures such as subfloors and load-limiting seats are used in current aircraft; however, limited space inside the cabin can reduce their effectiveness. [6, 7] External devices do not have the same constraints. Because they are deployed externally from the aircraft, they can have large volumes available for energy absorption.

The DEA concept was originally proposed as a passive energy attenuation system for the NASA Orion crew module, which was designed to significantly reduce impact loads transmitted to the crew during land or water impact following capsule re-entry. Early in its development, the DEA concept demonstrated excellent energy absorption capabilities, and it was selected for further evaluation in aeronautics-based applications. The DEA concept utilizes an expandable composite honeycomb structure to dissipate kinetic energy through crushing and incorporates a unique flexible hinge design that allows the honeycomb to be packaged and stowed flat until needed. A variety of deployment options such as linear, radial, and/or hybrid methods can be used, as depicted in Figure 1. Several deployment methods were studied with the goal of achieving equivalent deployment times as external airbag systems. Since 2006, experimental evaluation of the DEA utilized a building block approach that began with material characterization testing of its constituent, Kevlar™ fabric/epoxy, and concluded with a full-scale crash test of a retrofitted light helicopter under combined velocity conditions. At each stage of the testing, finite element simulations were performed using the explicit nonlinear transient dynamic code, LS-DYNA®.

The crash test article was an MD-500 helicopter that was donated by the US Army. The helicopter was retrofitted with two fully-deployed DEA blocks attached to the bottom skin of the helicopter, beneath the crew and passenger compartments, as shown in Figure 2(a). Four crash test dummies, two crew and two passengers, were instrumented to provide occupant response data. One of the dummies was a special Human Surrogate Torso Model (HSTM) that contained simulated internal organs and was provided by the Johns Hopkins University Applied Physics Laboratory in Laurel, MD. [8] This special occupant was included to assess the likelihood of soft tissue injuries. The final test article weighed 2,930 lb, which is slightly less than the maximum gross take-off weight (3,000-lb) of the vehicle.

The crash test was performed by suspending the helicopter from the LandIR facility at a height of 35-ft

Figure 1 Photographs Showing Linear and Radial Deployment of the DEA

Figure 2 (a) Pre-Test and (b) Post-Test Photographs of the MD-500 Helicopter

using swing and pullback cables. At release, the pullback cables were pyrotechnically severed, allowing the test article to swing to the ground pendulum-style. Pyrotechnic devices were used cut the swing cables just prior to impact. Motion-tracking photogrammetry techniques were used to determine the attitude and velocity of the test article at impact. [9] The vehicle attitude at impact was 5.7° pitch, 9.3° yaw and 7.0° roll. On impact, the helicopter's skid landing gear bent outward, and the DEA blocks crushed effectively, as shown in Figure 2(b), even under higher-than-expected pitch and yaw conditions and a high forward velocity. Only minor damage to the aircraft was observed post-test including buckling of the forward skin panels and keel beam on the lower right side of the airframe. Data from the crash test dummies were compared with human injury risk criteria and the results indicated a very low probability of injury for this crash test. [10, 11]

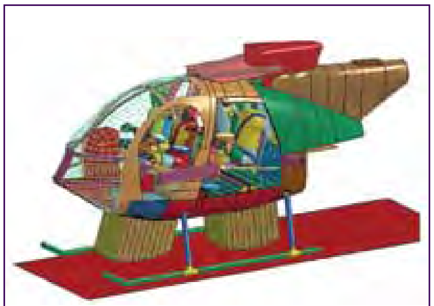

Figure 3 System-Integrated Finite Element Model of the MD-500 Helicopter

The acquired data were used to validate a system-integrated finite element model, shown in Figure 3. This 400,000-element model is designated "system-integrated" because it contains accurate physical representations of the airframe, skid gear, seats, occupants, restraints, ballast, DEA, and the impact surface. [12, 13] More than half of the elements in the model (266,000 shell elements) were used in representing the DEA. Previous convergence studies revealed that the maximum acceptable element length for the DEA was approximately 0.3 inches. This element edge length was needed in order to achieve accurate prediction of the cell wall folding pattern. The fuselage model contains 27,000 elements, with mesh refinement concentrated around the subfloor. The fuselage model is primarily composed of shell elements representing airframe skins, ribs and stiffeners. Ballast representing the rotor mass, tail mass, and fuel is incorporated as concentrated mass elements. Finite element models of the crash test

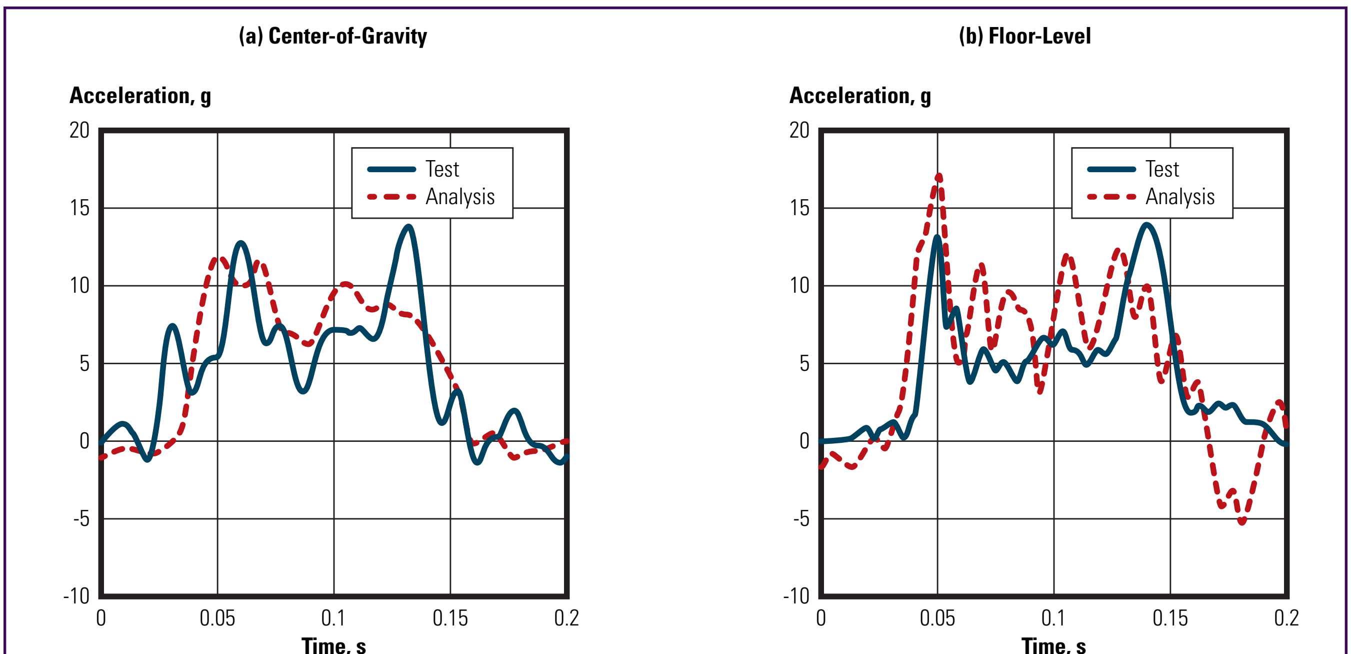

Figure 4 Comparison of Test and Analysis Vertical Acceleration Responses

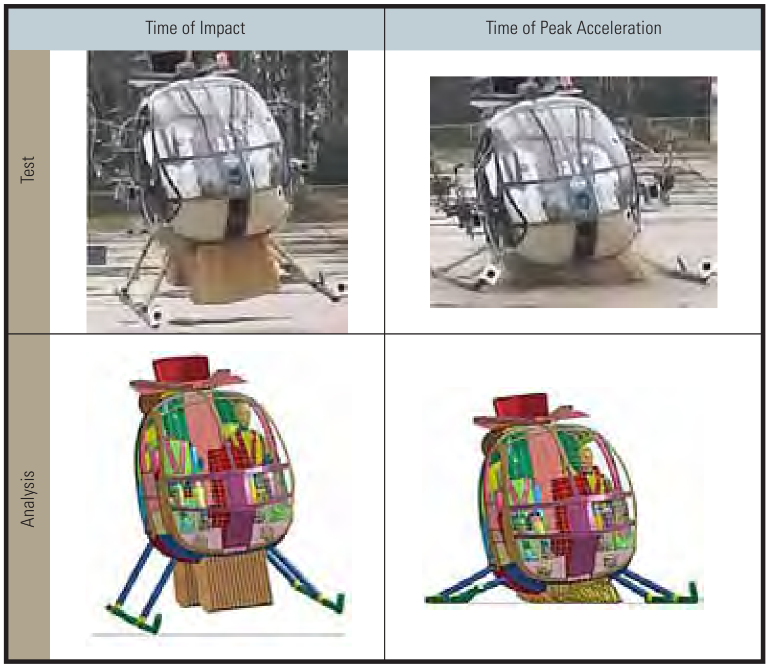

Figure 5 Comparison of MD 500 Deformations at Impact and at the Time of Peak Acceleration

Figure 6 Photograph of the Second MD-500 Helicopter Crash Test, without DEA

dummies were obtained from Livermore Software Technology Corporation (LSTC), the company that develops and markets LS-DYNA®. The dummy models contain mostly rigid representations of the individual components. However, some parts within the dummy models can be defined as deformable including the ribcage, chest jacket, and pelvis. The dummy models are easily imported and positioned within the LS DYNA® pre-processor. Each occupant model contains 4,295 elements with a wide range of element types and joint definitions.

Test-analysis correlations, shown in Figures 4(a) and (b), indicate excellent prediction of the vehicle Center-of-Gravity (CG) and floor-level responses, respectively. In addition, the vehicle impact orientation and deformation at peak load is shown for the test and analysis in Figure 5. The global deformation pattern of the DEA is similar to the deformation observed in the high-speed video, primarily folding on the right side and crushing on the left side. This non-uniform crush pattern is attributed to the off-nominal attitude of the helicopter at impact. In general, the DEA folding, crushing, and sliding along the belly was captured with the shell based model.

As a result of the first crash test, the airframe sustained minor damage to the front right subfloor region. This damage was repaired and the airframe was used in a second full-scale crash test, this time without the DEA. For the second crash test, the MD-500 was configured in the same manner as the previous test and was subjected to similar impact conditions. Note that the skid gears, seats, and restraints were replaced with new hardware for the second test. A post-test photograph of the second test, which was conducted at NASA's LandIR facility in March 2010, is shown in Figure 6. Substantial damage was sustained, including: failure of the crew and passenger seats; keel beam and subfloor frame failures; outer skin buckling and rupture; bearing failures of the skid gear; and, buckling of the center bulkhead. Occupant response data were analyzed and compared with human injury criteria. Unlike the previous test where the probability of injury was very low, results for the second test indicate a high probability of injury. Average floor level accelerations were approximately 40-g for the second test without the DEA, which represents an increase of about 30-g when compared to the test with the DEA. A comparison of floor-level acceleration time-histories are shown in Figure 7 for the crash tests with and without the DEA.

The full-scale crash test of the MD-500 helicopter retrofitted with DEA was the final demonstration of the energy absorbing concept. This test represented a severe challenge for the energy absorber given the combined impact conditions with a high forward velocity component that would tend to apply high shear loads to the DEA. Even under these severe conditions, the DEA performed well. Subsequent analysis of the test data indicated a survivable, non-injurious impact entirely due to the presence of the deployable energy absorbers. Finally, vehicle kinematics and structural acceleration responses were successfully predicted using a system-integrated finite element model. These results provide increased

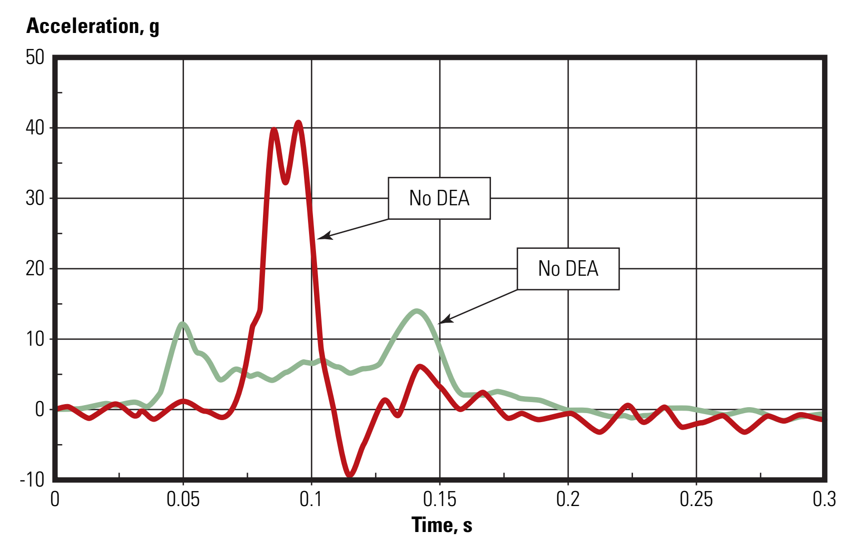

Figure 7 Comparison of Floor-Level Acceleration-Time Histories for Two Crash Tests, with and without the DEA

confidence in the application of transient dynamic simulation tools in predicting the crash response of rotorcraft and in the design of energy absorbing structures for improved crashworthiness.

Acknowledgements

The authors would like to acknowledge the US Army Special Forces and the Mission Enhanced Little Bird (MELB) Program for donation of the MD-500 helicopter for this research program. In addition, we acknowledge the Director, Operational Test and Evaluation (DOT&E) for financial support, and the Johns Hopkins University Applied Physics Laboratory (JHU-APL) for use of the human surrogate torso model. ■

About the Authors

Dr. Karen E. Jackson is an Aerospace Engineer working in the Structural Dynamics Branch of NASA Langley Research Center where she serves as team leader of the Subsonic Rotary Wing Crashworthiness Program. She received a doctorate in Engineering Mechanics from Virginia Tech in 1990. Dr. Jackson has authored or co-authored over 130 technical papers. She has won several prestigious awards, including the US Army Research Laboratory Technical Achievement Award for Engineering in 1999, and the H. J. E. Reid Award for best technical paper at NASA Langley Research Center in 2003 and 2009. Dr. Jackson was named a Technical Fellow of the American Helicopter Society in 2010.

Martin Annett is an Aerospace Engineer at NASA Langley Research Center. He received a BS degree in Aerospace Engineering and Mechanics from the University of Minnesota, and a MS degree in Mechanical Engineering from The George Washington University. He was previously employed at The Aerospace Corporation, Orbital Sciences Corporation, and The Johns Hopkins University Applied Physics Laboratory. He specializes in dynamic structural analyses, utilizing linear and nonlinear finite element analysis techniques. He has conducted shock, impact, and vibration tests, and has supported a variety of launch vehicle, spacecraft, and injury biomechanics programs. Mr. Annett is currently supporting aircraft crashworthiness research within NASA's Subsonic Rotary Wing Program.

References

1. Kellas S., "Deployable Rigid System for Crash Energy Management," US Patent Nos. 6,755,453 on June 29, 2004; 6,976,729 on December 20, 2005; and 7,040,658 on May 9, 2006.
2. Kellas S. and Jackson K. E., "Deployable System for Crash-Load Attenuation," Journal of the American Helicopter Society, Vol. 55, No. 4, October 2010, pp. 042001-1 through 042001-14.
3. Kellas S. and Jackson K. E., "Multi-Terrain Vertical Drop Tests of a Composite Fuselage Section," Journal of the American Helicopter Society, Vol. 55, No. 4, October 2010, pp. 042002-1 through 042002-7.
4. Yosef V., BenMoshe A., Noyman Y., Gansman B., and Bradney C., "Rotorcraft External Airbag Protection System," Proceedings of the AHS 62nd Annual Forum, Phoenix AZ, May 2006.
5. Bolukbasi A. O., "Active Crash Protection Systems for UAVs," Proceedings of the 63rd AHS Annual Forum, Virginia Beach, VA, May 1-3, 2007.
6. Taher S.T., et al., "A New Composite Energy Absorbing System for Aircraft and Helicopter," Composite Structures, 75, 2006, pp 14-23.
7. Desjardins S. P., "The Evolution of Energy Absorption Systems for Crashworthy Helicopter Seats," Journal of the American Helicopter Society, Vol. 51, No. 2, April 2006, pp. 150-163.
8. Roberts J.C., Merkle A.C., Biermann P.J., Ward E.E., Carkhuff B.G., Cain R.P. and O'Connor J.V., "Computational and Experimental Models of the Human Torso for Non-Penetrating Ballistic Impact", J. Biomech., 40 (1), 125-136 (2007).
9. Littell J.D., "Large Field Photogrammetry Techniques for Aircraft and Spacecraft Impact Testing," Proceedings of the SEM 2010 Annual Conference, Indianapolis, IN, June 6-8, 2010.
10. Kellas S., Jackson K. E., and Littell, J. D., "Full Scale Crash Test of a MD-500 Helicopter with Deployable Energy Absorbers," Proceedings of the 66th AHS Forum, Phoenix, AZ, May 11-13, 2010.
11. Littell J. D., Jackson K. E., and Kellas S., "Crash Test of an MD-500 Helicopter with a Deployable Energy Absorber Concept," Proceedings of the International Crashworthiness Conference, Leesburg, VA, September 22-24, 2010.
12. Annett M. S., and Polanco M. A., "System-Integrated Finite element Analysis of a Full-Scale Helicopter Crash Test with Deployable Energy Absorbers," Proceedings of the 66th AHS Forum, Phoenix, AZ, May 11-13, 2010.
13. Annett M. S., "LS-DYNA Analysis of a Full-Scale Helicopter Crash Test," Proceedings of the 11th International LS-DYNA Users Conference, Dearborn, MI, June 6-8, 2010.

Excellence in Survivability—Kevin Crosthwaite

by Donna Egner

The Joint Aircraft Survivability Program (JASP) is pleased to recognize Kevin Crosthwaite for Excellence in Survivability. Since 1993, Kevin has served as the Director of the Survivability Vulnerability Information Analysis Center (SURVIAC) located at Wright-Patterson Air Force Base, OH, which is operated by Booz Allen Hamilton. Kevin, a native of Ohio, graduated from Ohio State University (OSU) with a Bachelor of Science degree in Engineering Physics. He continued his studies and obtained a Master of Science degree in Nuclear Physics, also from OSU, and he is a licensed professional engineer in the state of Ohio.

Before joining Booz Allen Hamilton, Kevin was employed at a major defense contractor and hardware manufacturer where he was exposed to different systems and key technologies in a small operations analysis group. He defined performance requirements for several new and derivative weapon system concepts. He employed several models and simulations, building the models himself or modifying existing models. He also developed a methodology to quantify trade-offs between multiple disparate aspects of system performance. Kevin directed several internal research and development efforts using requirements analysis or effectiveness enhancement. He planned and coordinated test procedures and objectives; developed and proposed tactics for weapon system employment; and developed and proposed an Army unit force structure to man, maintain, and support new weapon systems.

Kevin joined the SURVIAC in its infant stages in 1985 when it was less than a year old. He began this stage of his career as SURVIAC's primary model analyst and has been the major proponent to making the survivability/vulnerability modeling program what is today. Kevin also brought experience in operations analysis, focusing on operations analysis of tactical anti-armor and air defense missile systems and combat analysis for fixed wing aircraft, helicopters, unmanned aerial vehicles (UAV), and ground systems. In these areas, he has led survivability and effectiveness analyses to support requirements definition for development and production weapon systems and to evaluate cost effectiveness of various system options. He coordinated SURVIAC model support efforts and major tasks on reducing aircraft vulnerability to the Man Portable Air Defense System threat and has led analysis of C-130 vulnerability to a variety of threats. Since Kevin has been at the helm, SURVIAC has grown to over 500 delivery orders valued at over $3B. Last year alone on the 160 open active delivery orders SURVIAC was funded at over $400M for critical technical work supporting the Department of Defense (DoD) and the warfighter. Inquiries since 1993 have numbered in excess of 16,800. These facts and figures have made SURVIAC the largest and most successful of the ten Defense Technical Information Center Information Analysis Centers. He has worked as a member of the Joint Aircraft Survivability Program Office (JASPO) and Joint Technical Coordinating Group Munitions Effectiveness (JTCG/ME), and currently serves as the secretary of the Combat Survivability Division of the National Defense Industrial Association (NDIA). He has participated in JASPO Methodology Subgroups and provided recommendations of the needs of the survivability community for numerous JASPO projects. Kevin supports the JASPO and JTCG/ME methodology groups to enhance the survivability discipline and coordinate the growth of SURVIAC throughout the DoD.

Mr. Crosthwaite has also had a full career in the Army National Guard and Reserves. He has served as an Armored Cavalry platoon leader, Troop XO, Rifle Company commander, and CESO at the Bn, Bde, JTF, and state levels. He also served as a separate Brigade IG. He was a reserve LTC on the J6 staff at USCENTCOM. He has completed Armor Officer Basic, Infantry Advanced, NBC training, Electronic Warfare staff officer training, and Command & General Staff schools.

Kevin and his wife, Diane, live in Marysville, OH, on a farm with numerous sheep, goats, cats, and a Saint Bernard named Heidi. They have five children, and four grandchildren. Kevin enjoys farming, running, home renovation projects, and rooting for OSU. He is active in church activities and serves as Vice President of North Union Local School District Board of Education where he has served since 2002.

It is with great pleasure that the Joint Aircraft Survivability Program (JASP) honors Kevin Crosthwaite for his

Continued on page 31

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Lightweight, High Performance Aircraft Fuel Bladders

by Kenneth Heater, Jon Macarus, Ryan Watts, and Bryan Pilati

The objective of this effort is to develop and qualify a lightweight fuel cell design that is significantly lighter than current constructions, yet remains compliant with all MIL-DTL-27422D requirements for flexible, crash-resistant, ballistic-tolerant fuel tanks (Type I, Class A). At the present stage of the development, the exoskeleton design concept described in this paper has been shown to be fully compliant with MIL-DTL-27422D Phase I Design Verification Tests, including critical gunfire and drop test requirements, with a 30% reduction in weight for the Phase I test cube configuration. The lightweight exoskeleton absorbs and redistributes loads during impact, so the number of fabric reinforcement layers required to meet impact requirements can be reduced.

The pressure to reduce weight while maintaining performance and safety is a significant driver in aviation technology development programs. This is particularly true for fuel and auxiliary equipment, which are major contributors to weight on aircraft. While fuel capacity is dictated by mission profile, the weight of auxiliary equipment (including fuel cells, fittings, access panels, and support structures) is dictated by design requirements to (i) integrate the fuel cell into the aircraft structure, (ii) facilitate access and maintenance, and most importantly (iii) protect the warfighter in the event of a crash or assault.

The fuel cells are a significant weight contributor and an obvious target for weight reduction programs as (i) aircraft typically contain multiple fuel cells, and (ii) the basic design and construction of the fuel cell has not changed significantly in modern times. Current flexible fuel cell designs consist of three major components: (i) an inner fuel containment section; (ii) a self-sealing core for gunfire resistance; and (iii) a series of outer plies for crash impact performance. The governing specification for flexible, crash-resistant, ballistic-tolerant aircraft fuel cells is MIL-DTL-27422D (Type I, Class A). Ballistic protection levels are further defined in the specification, with Level A (completely self-sealing against .50 caliber and 20 mm AP entry wounds) being the protection level of interest to the current effort.

MIL-DTL-27422D qualification requirements are divided into two major test phases to support fuel cell development and qualification efforts. Phase I Design Verification Testing, as provided in Sections 4.4 and 4.5, is conducted using laminate constructions for panel level testing, followed by a standard Phase I test cube design for structural level testing. Fuel cell designs demonstrating compliance with the Phase I test requirements are subjected to Phase II Testing as provided in Section 4.7. Phase II testing is a design qualification test, where an aircraft-specific fuel cell is built and tested in accordance with an approved Design and Procurement Specification such that, upon passing, the resultant fuel cell is approved for aircraft system integration.

This paper describes the development of a lightweight fuel cell design and concomitant Phase I Design Verification Testing. The present effort focuses on the development and integration of a lightweight exoskeleton to absorb and redistribute impact loads, so the number of fabric reinforcement layers

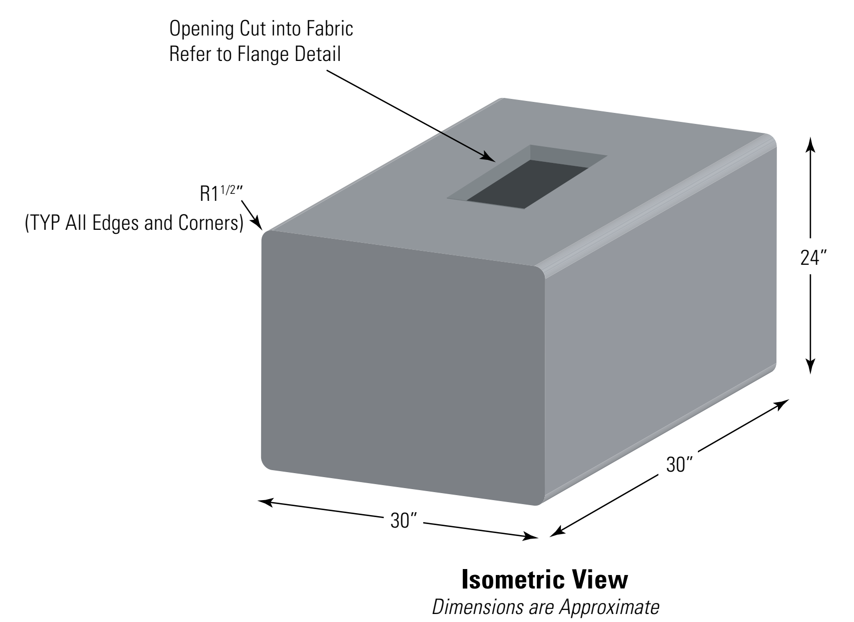

Figure 1 MIL-DTL-27422D Phase I Test Cube Schematic

necessary to meet the crash resistance requirements can be reduced. While the lightweight fuel cell design has been shown to be compliant with all of the Phase I requirements provided in Sections 4.4 and 4.5 of MIL-DTL-27422D, crash impact and gunfire testing (as provided in MIL-DTL-27422D, Sections 4.5.8.2 and 4.5.8.4, respectively) were emphasized in the development and qualification of the lightweight fuel cell. These efforts are described in this paper.

Fuel Cell Development

The baseline fuel cell design is presented in this section, followed by a description of the lightweight fuel cell design, including a comparative description of the Phase I test cube panel wall constructions. Comparative data are provided to demonstrate weight reduction potential based on the actual Phase I test cube construction (lb), as well as panel wall constructions (lb/ft²).

Baseline Design

The baseline design for the technology development efforts was the 4-ply MIL-DTL-27422D Phase I test cube. The Phase I test cube measures 30x30x24 inches, with a single oval fitting in the top panel with an inside opening measuring 10x6 inches (the actual fitting measures 16x10 inches, including the portion bonded into the top laminate structure). A schematic of the Phase I test cube is provided in Figure 1. A picture of a completed test cube showing the top panel with fitting is provided in Figure 2.

The baseline 4-ply, self-sealing, crash-resistant fuel cell construction is provided in Table 1 along with approximate contributions to the weight of the fuel cell based on areal density (lb/ft²). A schematic representation of the 4-ply fuel cell design is presented in Figure 3. The Phase I test cubes manufactured to support this effort used 120 mils of natural gum rubber for self-sealing capability. The reinforcement plies consisted of calendared sheets of fabric-reinforced nitrile.

Table 1 Baseline 4-ply Fuel Cell Construction

Component	Areal Density [a] (lb/ft²)
Inner Liner + Fuel Barrier	0.074
Self-Sealing Layer (120 mil)	0.500
Reinforcement Ply #1 w/tie layer	0.236
Reinforcement Ply #2	0.181
Reinforcement Ply #3	0.181
Reinforcement Ply #4	0.181
Total Panel Density	1.353

[a] *Areal density includes cement layers.*

The laminate construction is hand-laid over a form, with cement tie layers and adhesives used between layers and to secure joints, corners, and edges. The cube is a four-panel construction consisting of top and bottom panels and two side panels that wrap around opposite corners and meet at diagonally opposite corners. The location of the corner lap shear joints for the side panels is rotated 90 degrees with each ply such that each corner in the final cube consists of alternating wraps of continuous fabric reinforced rubber and lap shear joints (two of each). All of the joints used in the construction of the Phase I test cube are lap-shear joints measuring approximately 2.5±0.5 inches in overlap. A protective overcoat is applied for environmental protection.

Figure 2 Baseline Phase I Test Cube with Fitting

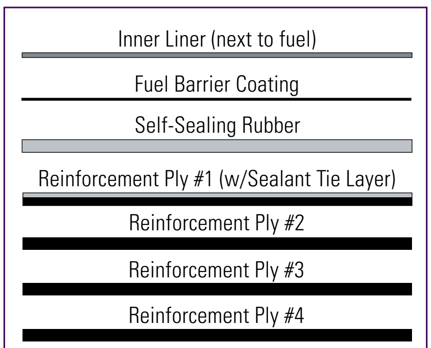

Figure 3 Baseline 4-Ply Laminate Construction

The laminated structure is vacuum-bagged and cured in an autoclave to produce the final part. As manufactured, the 4-ply Phase I test cube weighs 58 lbs (including the fitting flange but not the cap).

Lightweight Design

The lightweight Phase I test cube design is based on a 2-ply laminate construction, but using a lightweight, high-strength 'exoskeleton' to replace two of the crash-resistant fabric reinforcement plies. The basic construction of the lightweight fuel cell design is provided in Table 2, along with approximate contributions to weight based on areal density (lb/ft²). As manufactured, the 2-ply Phase I test cube with exoskeleton weighs 40 lbs (including the fitting flange but not the cap), a 31% weight reduction compared to the 4-ply baseline design.

Table 2 Lightweight 2-ply Fuel Cell Construction

Component	Areal Density [b] (lb/ft²)
Inner Liner + Fuel Barrier	0.074
Self-Sealing Layer (120 mil)	0.500
Reinforcement Ply #1	0.181
Reinforcement Ply #2	0.181
Exoskeleton	0.045
Total Panel Density	0.981

[b] *Areal density includes cement layers.*

A schematic representation of the lightweight fuel cell design is presented in Figure 4. A picture of a lightweight test cube with exoskeleton is provided in Figure 5. The exoskeleton is applied to the Phase I test cube as an additional manufacturing step after fabrication and curing. The exoskeleton is designed to absorb and redistribute loads during impact so the crash impact requirements can be met using the lighter weight construction. In the current configuration, the exoskeleton is constructed from netting fabricated out of Dyneema® ultra high modulus, ultra high molecular weight polyethylene fibers. The Dyneema® fibers have a density of 0.97 g/cm3, with the final netting configuration providing a weight contribution of 0.045 lb/ft². Other configurations, including lightweight fabric weaves, strapping, *etc.*, can provide a similar result.

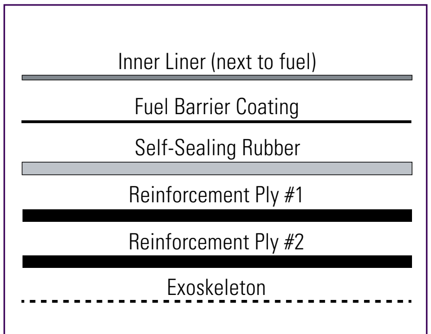

Figure 4 Lightweight 2-Ply Laminate Construction

Figure 5 Lightweight Phase I Test Cube with Exoskeleton

The basic construction of the lightweight fuel cell is the same as the four panel construction used for the 4-ply design with two notable exceptions: (i) the inner reinforcement ply does not contain a tie layer of self-sealing rubber, and (ii) the lap shear joints on the side panels are not located along the corner edges of the cell. In the 2-ply design, both of the fabric reinforcement layers are comprised of nitrile reinforced rubber and a cement tie layer is sprayed onto the self-sealing layer to provide adhesion between the sealant and the crash-resistant outer plies. The main reason for this adaptation was to ensure that all of the lap shear joints used in the construction of the lightweight Phase I test cube consisted of nitrile-to-nitrile bonds; a design element that was found to be crucial to the crash impact performance of the lightweight fuel cell design. The location of the of the lap shear joints was also found to be influential in drop test performance. Conventional placement of the lap shear joints along the edges of the test cube yielded mixed results during drop impact testing of the lightweight fuel cells, with intermittent failures occurring immediately adjacent to one of the corner edges. This behavior is believed to be due to the relatively sharp transition that occurs from plane stress to plane strain as the stresses incurred during drop impact propagate from the relatively flexible faces of the test cube to the more reinforced, and hence more constrained, corners of the cube. Moving the location and/or orientation of the lap shear joints away from the corners and into the face of the test cube proved to be crucial in addressing this problem for the lightweight fuel cell design.

Fuel Cell Testing

Fuel cell testing included Phase I Design Verification Testing as prescribed in MIL-DTL-27422D, Sections 4.4 and 4.5. While the lightweight fuel cell design was tested and shown to be compliant with all of the Phase I test requirements, due to the design elements being altered, emphasis was placed on crash impact (Section 4.5.8.2) and gunfire testing (Section 4.5.8.4), which are the most critical tests for crash-resistant, ballistic-tolerant fuel cells. All of the crash impact and gunfire testing performed in support of this effort were conducted by AMFUEL at their manufacturing and test facility located in Magnolia, AR. Final qualification testing was witnessed by appropriate representatives from the US Army Aviation Engineering Directorate (AED) and Aviation Applied Technology Directorate (AATD).

Crash Impact Testing

Crash impact testing for the Phase I test cube designs was conducted in strict compliance with MIL-DTL-27422D, Section 4.5.8.2 requirements. In each test, the test cubes were filled with 770 pounds of water (92.4 gallons using a calibrated water meter). The air was removed from the test cubes as the cover plate was attached to the fitting. The cubes were then placed on a rigid platform that allowed the fuel cell to be lifted to a height of 65 feet (as measured from the bottom of the cube to the ground). Cable guides were used to ensure that the bottom of the test platform and fuel cell remained parallel to the ground so that, upon release and impact, the test platform and fuel cell impacted the concrete test pad in the horizontal position (a variance of 10 degrees is allowed). High-speed video cameras were set up to verify horizontal impact and to record the results of each drop test and. A picture of a fuel cell being raised on a test platform is provided in Figure 6.

Crash impact testing was conducted on a number of Phase I test cubes to support the lightweight fuel cell design efforts. For illustrative purposes, the results of three drop tests are provided in this paper, with two pictures provided for each test: one taken almost immediately upon impact and the other taken shortly after impact to demonstrate energy absorption (unaffected cells demonstrate a significant bounce after a successful drop impact).

The first drop test, depicted in Figure 7 top and bottom photos, shows the catastrophic failure at impact of a 2-ply

Figure 6 A Phase I Test Cube Being Raised on a Test Platform to a Height of 65 ft Prior to Drop Impact Testing

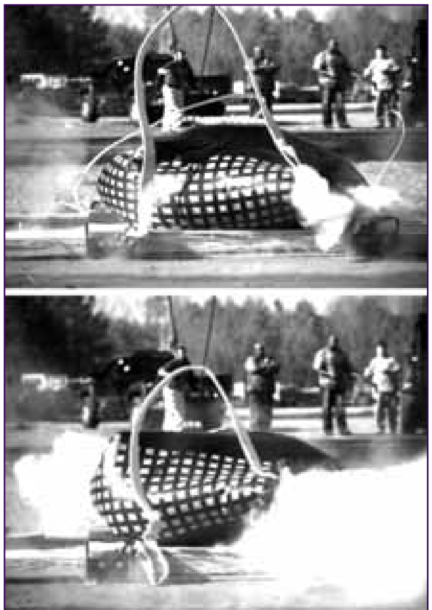

Figure 7 Crash Impact Failure of a 2-Ply Lightweight Phase I Test Cube without Exoskeleton

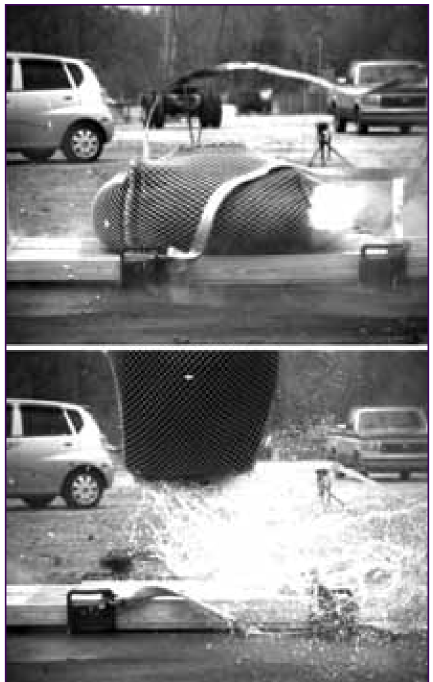

Figure 8 Crash Impact Failure of a 2-Ply Lightweight Phase I Test Cube with Exoskeleton and Poor Joint Design

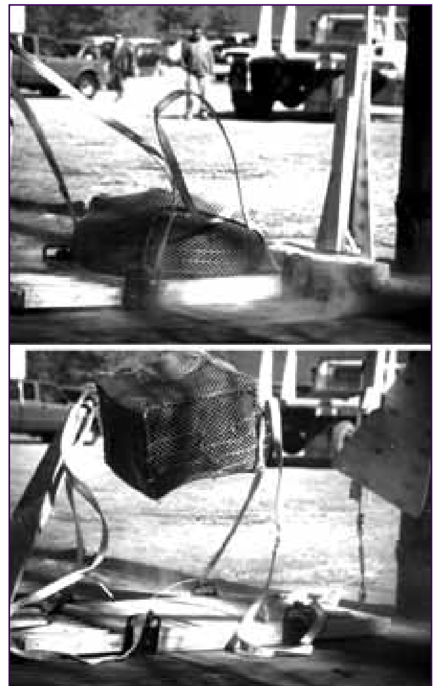

Figure 9 Qualified Crash Impact Test Result for Final 2-Ply Lightweight Phase I Test Cube Design with Exoskeleton

lightweight Phase I test cube without the exoskeleton (the grid pattern is painted on for video analysis purposes). Note the rupture occurring along the entire corner edge of the under-designed cell, completely blowing out opposite corner edges of the Phase I test cube with no rebound effect.

The test results depicted in Figure 8 for an intermediate 2-ply lightweight fuel cell design with exoskeleton are much better. While still failing the drop impact test, the fuel cell exhibits only a local tear along in the face panel adjacent to the corner edge, maintaining enough integrity as a unit to absorb a significant portion of the impact energy and bounce after impact. The results of tests like the one depicted in Figure 8 ultimately led to the development of alternate lightweight fuel cell constructions where the location and/or orientation of the lap shear joints in the side panels was moved away from the corners and into the faces of the test cube.

The crash impact test result for the 2-ply lightweight fuel cell design with exoskeleton is depicted in Figure 9. The lightweight Phase I test cube design is 30% lighter than the baseline 4-ply construction yet still passes the 65-ft drop impact test. The fuel cell demonstrates significant deflection upon impact and bounces back without any visible damage to the test cell.

In addition to the new energy-absorbing exoskeleton, the qualified fuel cell design was constructed with the side panel lap shear joints located in the faces of the test cube. This is believed to be beneficial in two respects: (i) it removes the discontinuity in stiffness and constraint associated with the conventional placement of the lap shear joints at the corner edges; and (ii) positioning the lap shear joints in the faces of the cube allows more energy absorption to occur due to the unconstrained deflection across the largest surface area of the cube (the faces); thereby reducing loading across the lap shear joints.

Gunfire Testing

Normal temperature gunfire testing was conducted in accordance with Section 4.5.8.4.3 of MIL-DTL-27422D. The lightweight fuel cell design was required to maintain gunfire protection to Level A. Level A protection requires entry and exit wounds to seal with aligned and tumbled .50 caliber rounds, and entry wounds to seal after an aligned 20 mm armor-piercing (AP) hit.

For gunfire testing, the test cell was placed in a metal structure as required for Class A fuel cells, and a backing board was used. The test cell was filled ¾ full with iso-octane and pressurized with CO_2 (for explosion prevention), but the cover plate was only loosely attached to prevent over-pressurizing the cell. All shots were fired at least 6 inches below the fuel line and 3 inches from the corner edges of the cube. The entire fuel cell test structure was rotated for the 45 degree shot. The sequence of the gunfire testing is provided in Table II of MIL-DTL-27422D. The test fluid was drained after each shot and the entrance and exit wounds were plugged prior to the next shot. As required, the firing distance was less than 75 feet, and a chronograph was used to measure the muzzle velocity of each round fired. Wooden boards were used as tumbling plates for tumbled shots.

The Phase I test cube constructions subjected to gunfire testing were consistent with lightweight 2-ply design provided in Table 2. An initial design using 60 mils of self-sealing natural rubber was tested but did not seal the .50 cal tumbled rounds. However, the lightweight construction which was qualified in the crash impact test (having 120 mils of natural gum rubber) demonstrated compliance with all Level A requirements. The qualification test results for the lightweight fuel cell construction are provided in Table 3. The muzzle velocity of all .50 cal shots was greater than 2500 ft/s. The muzzle velocity of the 20 mm AP round was not recorded.

Table 3 Normal Temperature Gunfire Test Results

Shot Description	Result (Entry/Exit)
.50 cal, 90°, straight	Dry Seal, No exit
.50 cal, 90°, tumbled	Damp Seal, No exit
.50 cal, 90°, tumbled	Damp Seal, Damp Seal
.50 cal, 90°, tumbled, repeat	Dry Seal, Damp Seal
.50 cal, 45°, straight	Dry Seal, No exit
20 mm AP, 90°, straight	Entry Wound Sealed

Conclusions

The ability to develop and qualify a lightweight fuel cell that is 30% lighter than current fuel cell constructions, yet remains compliant with all MIL-DTL-27422D requirements for flexible crash-resistant, ballistic-tolerant fuel tanks (Type I, Class A), has been demonstrated. Critical design elements of the lightweight 2-ply fuel cell design include: (i) the use of a lightweight, high strength exoskeleton to absorb and redistribute loads during crash impact; (ii) cured nitrile-to-nitrile bonds in all lap shear joints for maximum strength; and (iii) repositioning of the lap shear joints from the corners edges to the faces of the test cube to reduce plane strain related failures. The lightweight exoskeleton design described in this paper is currently being adapted and qualified for use on the AH-64 main fuel tanks. The AH-64 development, testing, evaluations and qualification efforts are being conducted in full conformance with the Phase II Testing requirements of MIL-DTL-27422D as provided in Section 4.7. The Phase II testing will be conducted in accordance with a qualification test plan approved by the AED. Additional weight reduction initiatives are targeted at replacing or reducing the use of the natural gum rubber sealant using new synthetic rubber sealing materials. The natural gum rubber sealant contributes 17 lbs or 30% to the weight of the Phase I test cube, making it a clear target for weight reduction considerations.

Acknowledgments

METSS would like to acknowledge funding and support provided by the following: AATD; US Army Small Business Innovation Research Program Manager; AED; Joint Aircraft Survivability Program (JASP); Apache Program Manager; and Program Executive Office – Aviation. ■

The lightweight fuel cell design described in this paper is the subject of US Patent Application No. 12/796,295.

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References

1. MIL-DTL-27422D, Detail Specification for the Tank, Fuel, Crash-Resistant, Ballistic-Tolerant, Aircraft, January 30, 2007.

Investigating Crew Compartment Fire Survivability

by Andrew Drysdale

The subject of this article is a joint Air Force-Army effort to improve the methodology of assessing occupant vulnerability to a sustained fire in an aircraft. Historically, the assessment of occupant vulnerability has been restricted to primary ballistic effects, *e.g.,* kinetic energy penetration or high-explosive blast. The scope of analysis methodology may neglect potential secondary effects that are less easily captured by testing. One example is the potential vulnerability of aircraft occupants to various environmental hazards associated with a threat-induced, sustained fire.

Fires in crew/passenger compartments are a possible outcome in threat encounters that involve flammable fluids and/or other combustible materials. For example, fuel lines may run much of the length of the fuselage in many fixed-wing transport aircraft and rotorcraft and are often vulnerable to ballistic threats because of both their size and relative "softness."

Historically, fire investigations have been largely restricted to determining probabilities of ignition and sustainability. In an effort to preserve the integrity of the test bed, a sustained fire would usually be declared if it lasted 10-15 seconds from ignition. The fire would then be immediately extinguished using supplemental means. This approach is useful for identifying sustainable fires so that assessments can be made of what aircraft systems would likely be damaged.

The methodology is limited, however, for measuring the secondary effects of a sustained fire on personnel. In many cases, it is simply assumed that the fire will be extinguished manually by the occupants and will not pose harm during flight or impede egress after landing. This is insufficient for accurately assessing occupant vulnerability, which can be affected by a sustained fire in several ways — specifically, through increased temperature and toxic fume exposure. In addition, the ability of the flight crew to operate the aircraft may be impeded by obscuring smoke, and the ability of the occupants to egress the vehicle may be limited by the location of the fire.

Therefore, a new test methodology is being developed under the Joint Live Fire (JLF) Air program by the Air Force (46th Test Group/OL-AC) and the US Army Research Laboratory's Survivability/Lethality Analysis Directorate (ARL/SLAD) to assess these secondary effects. In addition, the effectiveness of the occupants' firefighting techniques and equipment is being examined.

Task Overview

This project (JLF Air T-10-03) began in FY 2010 and will continue through 2011. The objectives are: 1) selection of an appropriately sized, reusable test bed for fire survivability analyses; 2) assessment of test methodology and apparati *via* baseline tests of typical combustible fluids; and 3) assessment of the effects of a sustained fire on the ability of occupants to operate the aircraft, extinguish the fire, and/or escape the vehicle. As of this writing, the test bed selection has been completed and modification is underway. Baseline testing and various additional tests are scheduled for completion later in FY 2011.

Test Bed Selection and Modification

Since crew compartment fire survivability is an issue for most large rotary- and fixed-wing aircraft, it was desirable that the test bed be designed with the ability to accommodate multiple aircraft designs. A retired HH-3 helicopter, provided by ARL, was selected as the test bed. Several modifications were made to the helicopter: the sponsons and vertical pylon were removed and custom landing gear was added to simplify the transportability and maneuverability of the fuselage (Figure 1) between test sites.

A steel pan will be fitted above the cabin floor (Figure 2) to prevent test fluids from seeping into subfloor spaces. This modification will greatly increase the life of the test bed by minimizing exposure of the floor structures to pool

Figure 1 HH-3 Fuselage Test Bed

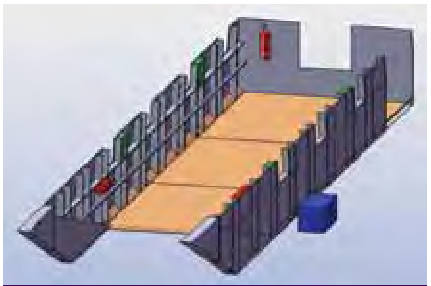

Figure 2 Conceptual Test Bed Interior with Steel Pans Covering Floor

fires. The pan is also designed to channel the liquid so that it is easily collected and removed from the test site.

In addition to the steel pan, a CO_2 system will be installed inside the fuselage to extinguish fires once data collection is completed.

The HH-3 is well-suited to represent a variety of fuselage interiors such as those of the C-27J Spartan, UH-60 Black Hawk, and CH-47 Chinook (Figure 3). The fuselage can be configured to represent the specific aircraft chosen for investigation as closely as possible. Passenger seating, additional equipment, and test-instrumentation locations can also be easily rearranged as necessary.

Capabilities

The HH-3 test bed will be equipped for two types of tests: 1) controlled damage tests, where a nozzle installed in the fluid line emits a spray that is ignited remotely; and 2) ballistic tests, where the fluid line is shot from behind a strike plate that represents the aircraft skin and ignition is spontaneous. Controlled damage tests are favored for initial validation of the test bed and methodology. Custom-designed nozzles will be used to simulate fluid leaks and can be adjusted to provide a wide variety of flow rates (leak severities) and pressures (dispersion areas). Appropriately sized pumps located outside of the test bed will be used to generate the desired flow rates and pressure in the lines.

Instrumentation

Two positions (fore and aft) will be defined on the HH-3 in order to standardize test events. Instrumentation will be configured to gather data at these three positions as effectively as possible.

Fire intensity and duration, internal temperature, and atmospheric composition will be the data given greatest emphasis, unless a specific test situation requires otherwise. Standard and high-speed video recording equipment will be installed for monitoring test events.

Initially, a three-dimensional "grid" of thermocouples will be constructed and installed throughout the fuselage. Each cross-section of the grid will contain an array of thermocouples at varying distances from the fuselage walls. This cross-section pattern will be repeated at multiple stations from fore to aft within the fuselage. Additional thermocouples will be placed in critical locations, for example at occupant locations, or near the fire ignition site, as required.

Figure 3 HH-3 Fuselage Interior

Toxic fume sensors will be deployed at positions likely to be occupied by personnel, at heights representative of their likely position, whether standing, seated, or prone. Fires will be monitored by video cameras mounted in several locations in and around the test bed, from the cockpit area to the rear of the crew compartment, and outside of the fuselage entirely. Some of these cameras will also record the occupant's view of the compartment to measure visibility. Fluid delivery will be monitored by pressure and flow transducers, ensuring correct functioning of the test bed.

Summary

The test bed developed by this program will serve as a flexible surrogate that can represent aircraft occupant compartments of both fixed-wing and rotorcraft designs. This flexibility is enhanced by the design of instrumentation fixtures to emphasize efficient re-positioning and the ability to "switch out" measuring devices when the test objectives change. Lessons learned in test methodology development look certain to expand the accuracy and applicability of aircraft live fire testing and occupant survivability assessment.

This capability will give survivability/vulnerability analysts the ability to more fully assess the hazard to aircraft occupants as a result of fires, broadening the scope of vulnerability analyses to more fully reflect the range of threats faced by aircraft occupants. Instead of "stopping" the analysis once fragment intersections and blast spheres have been calculated, it will be possible to play out the full threat-encounter scenario to include the consideration of secondary effects that the crew and passengers may be required to overcome. ■

About the Author

Mr. Andrew Drysdale is an aerospace engineer with six years experience at the US Army Research Laboratory at Aberdeen Proving Ground, MD. His professional interests include rotorcraft aerodynamics, rotorcraft design, and ballistic vulnerability analysis. He graduated from University of Maryland, College Park, in 2005.

Evolving Complexity in Rotorcraft Survivability Analyses

by Andrew Drysdale and Edwin Sieveka

The US Army, responding to a military-wide initiative, has recently increased its emphasis on the consideration of occupant injury during aircraft survivability/vulnerability (S/V) analyses. Since the optimum outcome scenario for the occupants is not necessarily the optimum scenario for the aircraft system and vice versa, the new emphasis must lead to an adjustment in the S/V analysis process itself. One consequence of this adjustment is the addition of several sources of complexity to the traditional analysis process.

The legacy process for Army S/V analyses of helicopters experiencing main rotor power loss centers around utilization of the DESCENT code. DESCENT is a two-dimensional rotorcraft autorotation model that iteratively optimizes the pilot's control inputs (and, accordingly, flight path) until the most benign landing conditions are discovered. This optimized impact velocity vector is then translated into an aircraft kill probability that is reported out to the overall analysis.

The DESCENT-based approach is satisfactory for assessing helicopter kill probability when the correlation between impact vector and damage is understood and there is a single damage modality (or combinable modalities) such as a critical component failure to assess. Consideration of occupant injury as a fully parallel modality necessitates a less straightforward process; as S/V analysis evolves, pure impact velocity optimization through DESCENT is becoming one part of a more comprehensive, recursive strategy that allows for significantly more feedback between rotorcraft design, operation, and mission planning, and increases the scope of factors applied to the analysis to more accurately predict both vehicle and occupant survivability.

DESCENT-Based Analysis as a Starting Point

The DESCENT-based analysis, shown in Figure 1, uses the aerodynamic and structural properties of the rotorcraft (and its initial flight conditions) to optimize pilot response to a power-loss event. That response helps determine the autorotation impact conditions and kill probabilities. Note that this is a largely one-way flow of information: DESCENT takes input data and optimizes values for the output quantities, and those values are then used in the survivability assessment.

There is, however, a limited capacity within this process for data feedback that might assist in mission planning and piloting technique refinement. This valuable aspect of the analysis process is represented by the blue arrow in Figure 1. Since the pilot's response is optimized during DESCENT's execution, the time-history of the rotorcraft's control settings represents information about how the ideal pilot acts under the applied modeling assumptions. Therefore, differences that exist between the DESCENT ideal, the autorotation "textbook" ideal, and the tendencies of real-world pilots performing an autorotation may be used as 1) an exploratory tool for improving pilot technique in unusual situations, or 2) an insight into how the model could be altered to consider a more realistic solution space of flight paths.

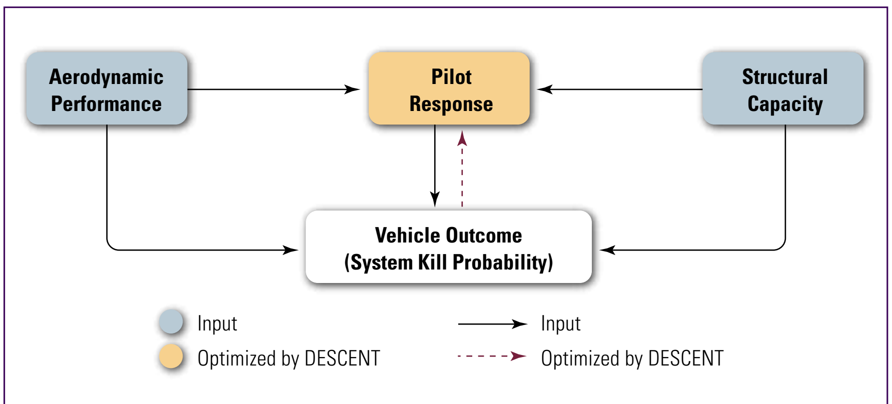

Figure 1 Data Flow in DESCENT-Based Damage Threshold Analysis

Even with limited avenues for feedback, a parametric analysis opens up opportunities for new insight into autorotation survivability. Consider just one quantity: pilot delay, the time it takes a pilot to realize that the main rotor is unpowered and react. A parametric variation of pilot delay will yield insight into how critical reaction time is at different parts of the flight envelope. Comparison of the output time-histories might then yield technique recommendations on how the autorotation maneuver should change as delay increases and subsequent correction becomes more challenging. If pilot-in-the-loop flight simulator tests are used to establish a baseline delay time, DESCENT could be constrained to analyze the survivability of rotorcraft under pilots of different levels of skill and/or experience. Further questions follow: do experienced and inexperienced pilots survive at similar

rates? Should they approach the autorotation maneuver similarly? Is a single kill probability sufficient for both groups? We see that even the DESCENT-based, vehicle-focused approach can go beyond simply calculating survival probabilities and have broad contributions to the fields of hardware design and technique development. The increased emphasis on occupant outcome provides an opportunity to expand on those contributions with the increased complexity of the analysis.

Occupant Injury: Developing a Structural Dynamics Approach

DESCENT's damage threshold inputs are usually calculated from the impact attenuation rating of the landing gear on a generic terrain; if the fuselage bottoms out, enough damage is sustained that attrition results. With the additional separate consideration of occupant injury—where occupants are in different positions throughout the aircraft and have different restraints—the acquisition of a single threshold becomes difficult, if not impossible. One proposed approach is the employment of a structural dynamics model of the rotorcraft to model loading on the occupants.

Structural modeling is seen to have applications divided into two broad areas: identifying scenarios in which the vehicle is assessed to have survived the impact but the occupants (because of posture, equipment, or other reasons) are unlikely to escape injury, and identifying scenarios in which the vehicle suffers an attrition but the occupants may nevertheless escape uninjured. The first application area may be somewhat "safer" because load paths, particularly in less detailed models, are more faithfully modeled in the elastic region. However, there is great interest in improving the crashworthiness of rotorcraft so that occupant injury is not a foregone conclusion even in cases where significant structural failure is predicted. This motivates simultaneous investigation of the second area.

Exploratory work done so far by the US Army Research Laboratory Survivability/Lethality Analysis Directorate (ARL/SLAD) and the US Naval Air Systems Command (NAVAIR) through Joint Aircraft Survivability Program (JASP) support has employed the MADYMO code that is used primarily in the automobile industry to predict crash outcomes. Inputs to MADYMO are a structural model of the helicopter, including detailed spring-mass-damper descriptions of seats and safety harnesses, a description of the terrain that influences the shape of the impact impulse, and the DESCENT-output impact state variables. Inside the rotorcraft model are placed simulations of Hybrid-3 mannequins that mimic the properties and measurement locations of standard crash test dummies. The MADYMO output is a loading history on the simulated mannequins. This history can be compared to injury criteria tables to determine the type and magnitude of injury sustained by the occupant.

Design and Technique Feedback Opportunities

As Figure 2 shows, the extra complexity of the MADYMO analysis step allows for a significant expansion of the opportunities for design and technique development feedback.

Data flow, as in the original process, begins with the aerodynamic and structural properties of the rotorcraft under analysis. Pilot response is optimized by DESCENT with the vehicle outcome in mind; *i.e.*, as before, with velocity thresholds determined by structural considerations. The same information about pilot response is gained.

The subsequent MADYMO analysis of occupant loading then incorporates additional data: the placement and restraint of passengers in the vehicle and the terrain over which the mission is executed. These new data sources are shown in yellow in Figure 2.

When MADYMO-based occupant loading predictions are matched to DESCENT-based vehicle damage predictions, a comparison is possible throughout the flight envelope. At the margins of the dead-man's curve, it is possible that unacceptable injuries might be predicted at a height (HAGL)-velocity flight condition where the rotorcraft was expected to survive. In effect, this is the identification of a new limiting factor on a comprehensive dead-man's curve for the combined vehicle-occupant system.

Safety features and techniques, together with pilot response, are a fertile ground for parametric analyses in the context of the enhanced S/V analysis. For example, DESCENT might predict that autorotation from a given point in the HAGL-velocity diagram is survivable for the rotorcraft, but MADYMO analysis predicts head injuries for a passenger in the rear of the aircraft. First, how would safety considerations affect the analysis? Perhaps a five-point restraint system would improve that occupant's impact loading. In cases of neck and lumbar loading, it may be possible that simply sitting in a different position can significantly mitigate injury. The importance of having stroking seats (throughout the cabin) and keeping them operable (instead of stowing gear underneath) is demonstrable. Next, how would pilot response affect the same situation?

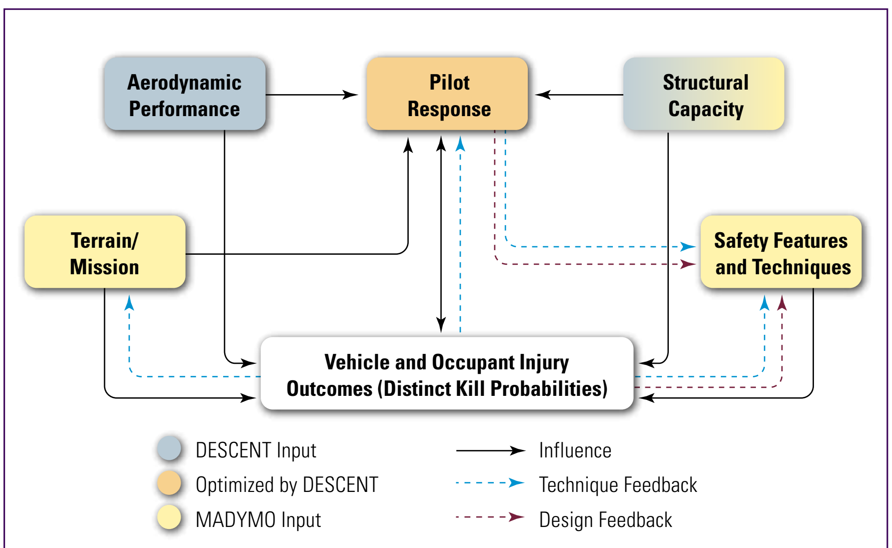

Figure 2 Data Flow with MADYMO-Based Occupant Loading Analysis

Modes of occupant injury such as whiplash are heavily dependent on factors such as fuselage orientation and pitch rate that are not normally first-order variables in the DESCENT analysis. It is easy to constrain DESCENT to land with a certain orientation or orientation rate of change and then optimize the landing with the most occupant-friendly impact state assumed. These constraints will lead to a flight path that is globally sub-optimal (for a vehicle-based objective), so it is important to know the differences in the new control history. Is there a way to autorotate the rotorcraft in a way that better prioritizes occupant outcome? Under what situations—and in which platforms—do these lessons apply? The opportunity for improving pilot response is significant.

Furthermore, the nature of the MADYMO input data lends itself to feedback opportunities. Design of a rotorcraft is complicated and expensive, to say the least, so it is difficult to recommend improvements to the aerodynamic or structural capabilities of a system. Thus, in the DESCENT analysis, pilot response is the only variable that is easily varied. But improvements to (or the simple inclusion of) safety features is a more accessible goal and one that can mitigate shortcomings in any of the DESCENT-input categories. Along the same lines, consideration of the effects of impact impulse might lead to relatively simple recommendations about the suitability of various types of terrain for autorotation maneuvers under different conditions.

MADYMO-Inclusive Process Feasibility Study

As a means of demonstrating the comprehensive approach, a notional analysis of a small helicopter was completed at the end of the JASP-sponsored effort. This was intended to quickly demonstrate that lessons learned by a structural dynamics analysis on a relatively simple rotorcraft model could be useful in the S/V context.

First, an exercise was done wherein an approximation of the Bell 206 was analyzed in DESCENT. The model simulated a total power-loss autorotation under arbitrary mission conditions and optimized the rotorcraft's impact velocity free of any additional constraints. Figure 3 shows the height-velocity diagram DESCENT output; green squares represent height-velocity initial conditions wherein an autorotative flight path could be found that satisfied the thresholds for a successful forced landing. Red squares represent conditions wherein the thresholds could not be satisfied and therefore the rotorcraft was seen to suffer attrition. The blue rectangle corresponds to the "low/slow" region used in traditional S/V analyses. As expected, the diagram conforms to a traditional "dead man's curve" for rotorcraft flight envelopes.

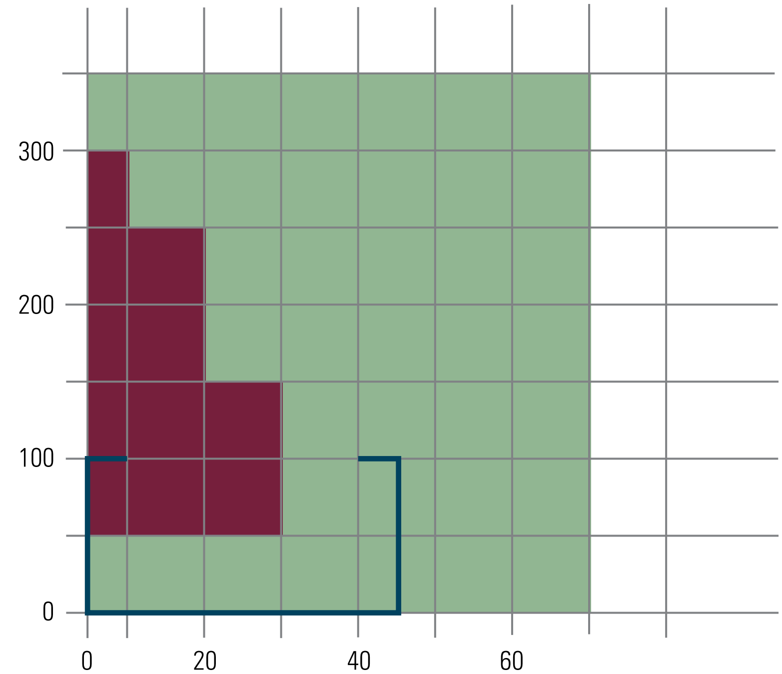

Figure 3 Autorotation Survivability vs. HAGL (in ft) and Initial Velocity (kts)

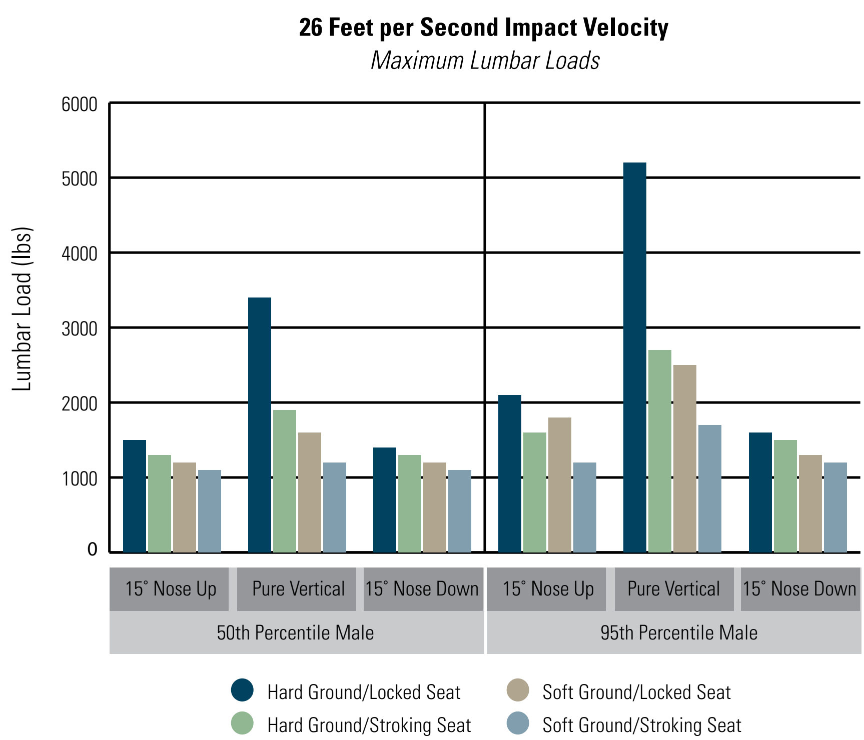

Figure 4 Effect of Fuselage Pitch at Impact on Lumbar Loads

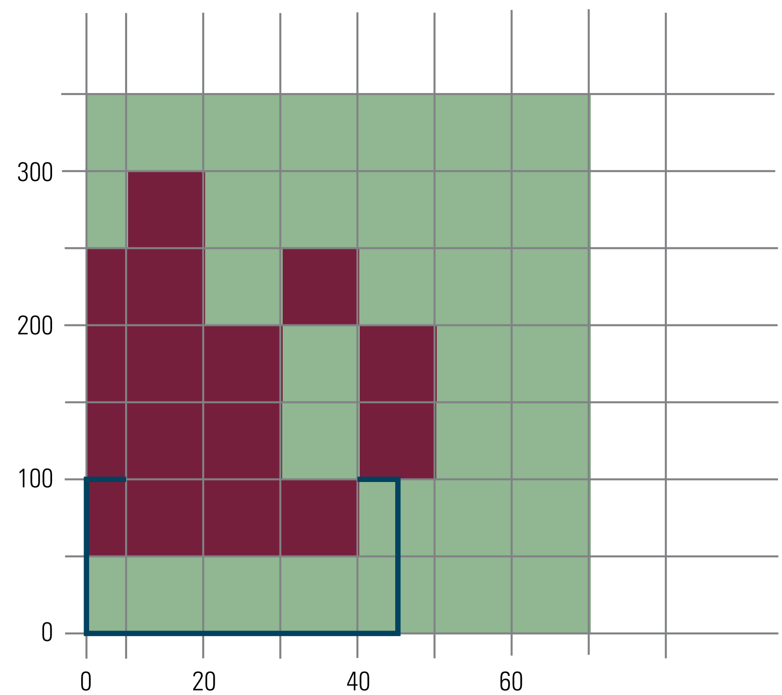

Figure 5 Constrained Survivability *vs.* HAGL and Initial Velocity

Second, a moderately detailed structural model of a Bell 206 was subjected to MADYMO impact simulations at horizontal and vertical velocities similar to those predicted by DESCENT at different points in the flight envelope. Of particular interest were velocities near the forced landing/attrition boundary; *i.e.*, near the attrition threshold velocities. Occupant loading was measured parametrically under variation of several situational characteristics (seat stroke capacity, occupant size, terrain conditions) and final state variables (fuselage orientation, velocity magnitude). This was done in order to investigate how to optimize occupant survivability under the general conditions predicted by DESCENT. Figure 4 shows a representative finding:

In all cases, a nose-down impact appeared to be significantly more survivable than a "flat" or nose-up impact. (It is hypothesized that in low horizontal velocity cases, a nose-down impact creates a lower-strain head motion than when the fuselage nose is raised. The purely vertical impact simply compresses the neck and spine.) Unfortunately, in many cases, the DESCENT-optimized flight path produced a final fuselage orientation that was nearly flat—the worst-case scenario. This suggests that some situations that are survivable for the vehicle are not survivable for the occupants and vice versa. To find the extent to which impact velocity optimization has to be compromised to avoid a flat landing, DESCENT was re-executed with an additional constraint on fuselage pitch that matched the optimal MADYMO scenario.

Figure 5 indicates the clear effect of the extra constraint—the rotorcraft's probability of experiencing attrition has increased in the vicinity of the low/slow region. Specifically, the probability of attrition has increased from 31% to 44%. This appears to be a significant trade-off in terms of vehicle survivability but represents the optimized outcome from the occupant standpoint and thus the most accurate picture of the survivability of the entire system. Other possible parametric considerations increase the degree of iteration in the process (Figure 2) but can be employed to ensure that each disparate aspect of the autorotation, from the pilot's training to the terrain profile, is accounted for in the final analysis.

Conclusions

The quest to both broaden the scope of criteria considered in S/V analyses and improve the accuracy of damage and injury prediction requires increasing complexity from the analysis process. There are significant advantages to be gained from using additional tools to iteratively improve pilot technique, occupant safety features, and terrain-oriented mission planning during the course of a DESCENT-based S/V analysis. It has already been demonstrated that such a process is viable and timely with available tools. It is through increased synthesis of this nature that the analysis process will reach its full potential, both in terms of its own applicability and its usefulness in influencing design and technique development considerations. ■

About the Authors

For information on Andrew Drysdale, please see page 24.

Dr. Edwin Sieveka earned a PhD in Engineering Physics from the University of Virginia (UVa) in 1983. He remained at UVa as a research scientist in the Mechanical Engineering Department, and became heavily involved in the computer modeling of human body crash dynamics related to automobile mishaps. In 2001, he moved to Maryland and joined the NAVAIR Crashworthy Systems Branch at the Patuxent River Naval Air Station. Dr. Sieveka guides a growing program that is using occupant dynamics modeling to enhance aircrew safety for a wide variety of Naval aviation mishap scenarios. He is particularly interested in developing a close, cooperative relationship between computer modeling and laboratory testing.

Flight Simulation of Damaged Transport Aircraft

by Gautam Shah

The threat posed by Man-Portable Air Defense Systems (MANPADS) to transport aircraft is one of growing concern worldwide. As evidenced by attacks on an Arkia Airlines aircraft in Mombasa, Kenya, in 2002 and a DHL cargo aircraft in Baghdad, Iraq, in 2003 (Figure 1), the threat is not limited to military operations, but is of concern to civil aviation as well. With the military's use of the Civil Reserve Aircraft Fleet (CRAF) to ferry troops, as well as increasing use of commercial derivative aircraft (CDA) for military applications, there is a relevant need to evaluate the survivability of such transport aircraft in the aftermath of a potential MANPADS encounter from the time of impact to the completion of a safe landing.

Figure 1 MANPADS Damage to a DHL Cargo Aircraft

Analyses conducted to assess vulnerability and overall survivability of aircraft subject to MANPADS damage have generally been focused on physical effects, *e.g.,* damage to the structure, vital components, and major systems such as hydraulics or fuel. For smaller tactical vehicles, such as fighter/attack aircraft, the resultant damage may often be catastrophic, or cause such severe stability or controllability problems so as to render the aircraft immediately unrecoverable. For larger transport aircraft, however, due to their sheer size and distributed systems, there is a greater chance that the aerodynamic or structural integrity, as well as controllability, while potentially being severely compromised, may not be affected catastrophically and adequate control may be available to allow a safe landing. Assessing the continued-flight capability, from an aerodynamic and controllability standpoint, of a transport aircraft to safely land with damage is of considerable interest and value because crew and passengers are generally unable to escape a transport aircraft in flight.

Research activity performed at NASA Langley Research Center in 2010, funded by the Joint Aircraft Survivability Program (JASP), addressed the issue of modeling and simulation of the aerodynamics, stability, and controllability of a large transport aircraft subject to MANPADS damage. The intent of the study was to provide a potential methodology for evaluating overall vehicle dynamics in the presence of MANPADS damage and to develop an understanding of modeling requirements for asymmetric damage effects on a transport aircraft. The study focused on several aspects of the issue at hand: determining representative and relevant damage conditions to model; estimating the aerodynamic effects of damage; modeling the effects in a real-time full-scale flight simulator; and conducting some basic piloted flight simulation to evaluate such a capability as a potential tool to augment survivability analyses. The study was conducted for a generic medium-range twin-engine transport aircraft, with a wingspan of approximately 125 feet and maximum gross weight in the 200,000-lb range (Figure 2). This configuration has been studied for over 10 years within the NASA Aviation Safety Program, and was chosen for this activity to leverage its extensive wind-tunnel, modeling, and simulation database.

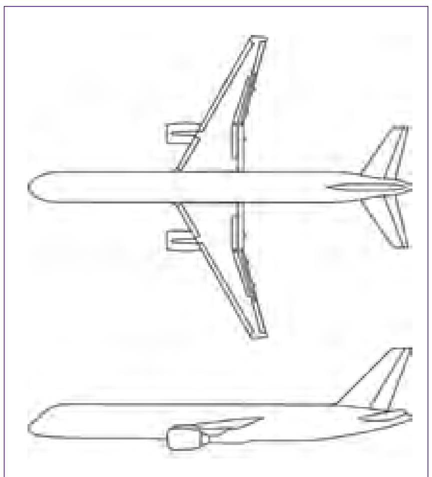

Figure 2 Generic Transport Aircraft Configuration

Because of the infinite number of potentially significant hit-point locations on a transport aircraft, as well as their disparate effects, the study focused on damage to one wing and,

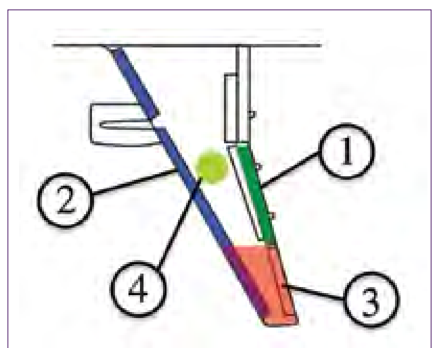

Figure 3 Selected Wing Damage Cases

further, primarily considered damage that would be expected to have significant controllability effects.

After a survey of MANPADS events and consultations with Department of Defense (DoD) survivability experts, four conditions were selected for modeling and simulation (Figure 3): 1) loss of an outboard trailing-edge flap; 2) loss of a leading-edge slat; 3) loss of the outboard ¼ of the wing; and 4) a large hole in the outboard section of the wing. The chosen conditions are representative based on a combination of actual events (such as the DHL cargo aircraft incident) and engineering judgment on possible damage that would have aerodynamic controllability implications on an impaired, but still flyable, aircraft. In all cases, the primary effect of the damage was aerodynamic roll asymmetry requiring varying levels of lateral control for compensation.

The aerodynamic effects of wing damage were obtained from the results of wind tunnel tests of the transport configuration with varying levels of damage. Force and moment data for static and dynamic (aerodynamic damping) characteristics were acquired for all three axes on a 5.5 % scale model in the NASA Langley 14- by 22-Foot Tunnel (Figure 4). This dataset augmented an extensive aerodynamic database for the basic transport configuration acquired over several years. Detailed results of the wind tunnel tests and a discussion of modeling issues for damaged aircraft have been published in AIAA-2008-6203, "Aerodynamic Effects and Modeling of Damage to Transport Aircraft."

A sample of the aerodynamic effect of damage to the left wing and its implications are shown in Figure 5 for wingtip and outboard flap loss. Due to lift loss on the damaged wing, a left-wing-down rolling moment is generated. As angle-of-attack increases (when speed decreases for level flight) the rolling moment coefficient grows and, despite the lower dynamic pressure from lower speed, the total rolling moment asymmetry increases. Therefore, increasing roll control (usually from ailerons and spoilers) would be required to maintain wings-level flight as the aircraft decelerates during approach to landing. If the amount of roll control required for a desired landing speed exceeds the amount available, control would not be possible and a higher (possibly unsafe) landing speed would be necessary.

The incremental aerodynamic effects of damage (changes in forces and moments in all three axes) were computed from the wind tunnel results and incorporated into a full 6-Degree-of-Freedom (6-DOF) simulation database of the configuration. The incremental effects were superimposed upon the baseline (undamaged) configuration as functions of angle of attack and sideslip. The baseline aerodynamic model is part of a real-time full-scale piloted simulation of the transport configuration.

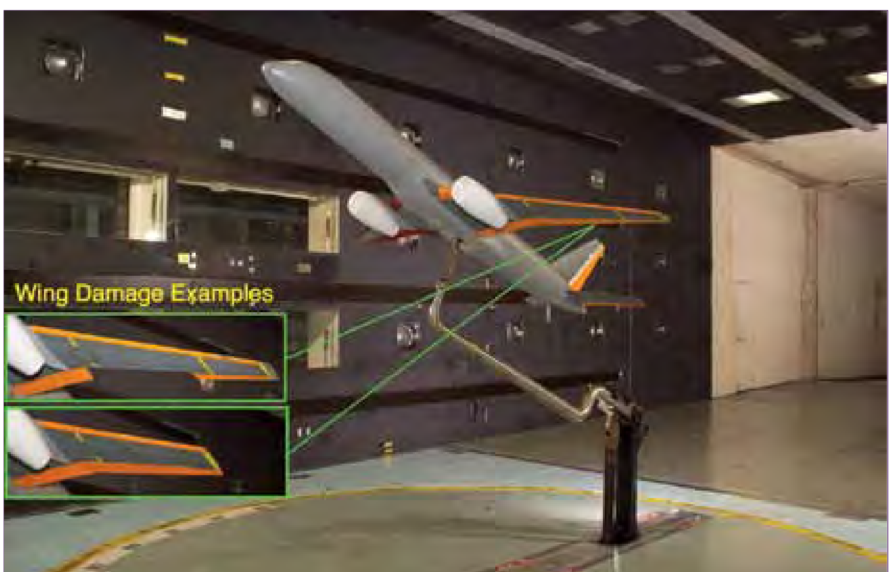

Figure 4 Transport Configuration in NASA Langley 14 by 22 ft Subsonic Tunnel with Representative Damage Conditions

Although the aerodynamic effects were the primary area of interest for this study, consideration was also given to modeling other aspects that would affect the flight dynamics of the vehicle, such as mass properties and control systems degradation. Physical loss of structure will result in changes to gross weight, inertia, and center-of-gravity location (laterally as well as longitudinally). Such mass property changes were modeled in a rudimentary fashion as an effect similar to the mass properties change that would be experienced due to physical loss of an engine. Reduced control capability resulting from damage to on-board systems such as hydraulics may take the form of lower actuation rates or diminished range of travel of various control surfaces. This type of effect was modeled as two discrete levels of degradation: 1) a 50 % reduction in the deflection rate of the aileron on the damaged wing, and 2) a total failure of the aileron on the damaged wing (surface frozen at zero deflection). While in reality a hydraulic-system degradation would be expected to have an impact on all control surfaces, the effects in this initial study were limited to the primary aspect – roll controllability with wing damage – hence only aileron effects were modeled.

The aerodynamic, mass properties, and systems effects were incorporated into the real-time full-scale piloted simulation, and were flown in various combinations:

- Aerodynamic changes alone
- Aerodynamic plus mass properties effects
- Aerodynamic plus mass properties effects, and control degradation.

Each of these combinations was flown at three flight conditions: low-altitude level flight; take-off/climb-out; and approach/landing. Each flight was started with the undamaged configuration and the damage effect was instantaneously applied after a short period of normal flight with trimmed thrust and controls.

Different aspects of controllability or maneuverability were studied for each type of flight condition. For the level-flight case, after damage was

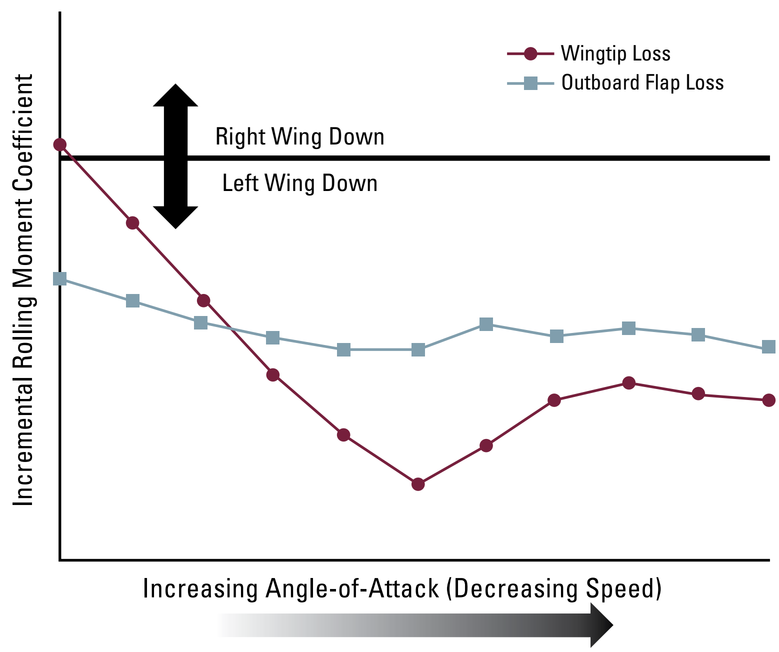

Figure 5 Incremental Rolling Moment Due to Wing Damage

applied, airspeed was decreased while maintaining constant altitude (thus increasing angle of attack) to observe the increasing roll control required to compensate for the aerodynamic roll asymmetry, and to define the limitations of that control. For the takeoff case, the ability to maintain level flight and complete maneuvers required to return towards the runway was studied. For the landing case, the aircraft was flown all the way to touchdown to observe the level of control needed as the aircraft decelerated during approach. In most scenarios, across all flight conditions, aerodynamic effects coupled with degraded control capability led to greatly compromised maneuvering capability. The need to maintain precise airspeed control at low speeds near touchdown and the utility of employing sideslip to compensate for roll asymmetry were found to be significant issues from a controllability standpoint. This effort was conducted from an engineering and simulation modeling perspective; further studies in this area would benefit from evaluations of transport-category pilots for issues on piloting techniques.

Preliminary analyses of the results demonstrated the significance of addressing the aerodynamic and control effects in the presence of MANPADS damage. Changes in control requirements during different phases of flight can be significant and should also be considered, *e.g.*, control sufficient for maintaining level flight may be insufficient for landing at a safe speed.

The study highlighted the potential importance of considering aerodynamics and control as part of an overall survivability assessment. It is entirely possible that, in damage cases where structural or systems integrity is degraded but not failed (and therefore survivable in those aspects), vehicle stability and controllability across the speed regime necessary to complete an approach and landing can be the deciding factor for the safe outcome of the flight. Full analyses of the data from this study are underway, and the results will be published in 2011. The technical approach used in this study will be applied in support of Joint Live Fire Engine-MANPADS testing in 2011 to evaluate post-damage safety-of-flight considerations for a transport aircraft. ■

About the Author

Mr. Gautam Shah is a Senior Research Engineer and Assistant Head of the Flight Dynamics Branch at the NASA Langley Research Center, Hampton, VA. He has been investigating flight dynamics issues for military and civil aircraft through wind-tunnel, simulation and flight research for 25 years. As a member of the NASA Aviation Safety Program team, he is the Technical Lead for vehicle dynamics modeling of transport aircraft in off-nominal conditions. Mr. Shah received a BS degree in Aeronautical Engineering from Embry-Riddle Aeronautical University, and a MS degree in Mechanical Engineering from The George Washington University.

Excellence in Survivability—Kevin Crosthwaite

Continued from page 16

Excellence in Survivability contributions to the JASP, the survivability community and the warfighter. ■

About the Author

Ms. Donna Egner has served as the Deputy Director for the Survivability/ Vulnerability Information Analysis Center (SURVIAC) located at Wright Patterson AFB, OH, since October 1991. Her association with combat data began in 1978 at the Combat Data Information Center (CDIC), the predecessor to SURVIAC. She oversees the day-to-day operation of the SURVIAC Core including technical/ bibliographic inquiries, library and combat database maintenance/ enhancement, and oversees promotional activities. Ms. Egner serves as a liaison between JCAT personnel, the Operation Enduring Freedom/Operation Iraqi Freedom combat data and the Information Technology personnel developing the Combat Damage Incident Reporting System (CDIRS).

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